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# 322

# TEMPERATURES OF LAKE MICHIGAN

## 1930-32

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## EXPLANATORY NOTE

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United States Department of the Interior, Fred A. Seaton, Secretary
Fish and Wildlife Service, Arnie J. Suomela, Commissioner

# TEMPERATURES OF LAKE MICHIGAN, 1930-32

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United States Fish and Wildlife Service
Special Scientific Report--Fisheries No. 322

Washington, D. C.
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## ABSTRACT

Lake Michigan temperatures were obtained at 136 stations, June 18-November 14, 1930, May 8-November 2, 1931, and April 19-September 12, 1932.

One hundred and fifty (150) series of vertical temperatures were obtained south of the Frankfort-Algoma line, 58 above this line in the lake proper, and 39 in Green Bay.

The text presents the data of relatively shallow and deep stations in nine regions covering the range of dates and depths, the seasonal changes of surface, subsurface, and bottom temperatures, the shifting of 5-degree water, and the depth intervals and thermal gradients of thermoclines. General comparisons were made of the temperatures of the various regions.

## INTRODUCTION

This report presents all records of the Lake Michigan temperatures obtained during the 1930-32 investigation described by Van Oosten and Eschmeyer (1956). This investigation was conducted primarily to determine how the destructiveness of small-mesh gill nets to immature lake trout might be reduced by such means as mesh size adjustments and the restriction of fishing to certain depths of water or areas. However, considerable information was also obtained on the other species of fish taken with the trout in the experimental nets. Only when time was available, the weather favorable, the lake relatively calm, and the currents not too strong, could samples of the bottom fauna, plankton, and bottom sediments be collected at the fishing stations, water temperatures recorded, and drift bottles released for the purpose of studying currents. Temperatures were not obtained at all of the 178 fishing stations or on every date at the 136 localities listed in table 1 and shown on the map (fig. 1).

Of the 247 series of vertical temperatures 150 were obtained in the area south of the Frankfort-Algoma line, 58 above this line in the lake proper, and 39 in Green Bay. Nearly all were taken between the hours of 7 a.m. and 12 noon: 97 percent in 1930 and 1931 and 89 percent in 1932. Because the temperatures were not uniform throughout the lake at all of the same depths, the data were compiled by local areas. Even in the same local region the temperatures may differ significantly on the same day. For example, on May 12, 1931, off the St. Joseph-South Haven shore a temperature of 5.2° C. (41.4° F.) was recorded at a depth of 37 meters (121 ft.) in shallow water and was observed also at the surface of a deep station, even though the two stations were only 8.2 miles apart on the vessel's course. Unlike in the small lakes, the thermocline of Lake Michigan was not always present in all areas at the same time or same depth. In this study a thermocline was considered a stratum of water where the centigrade temperature decreased at least one degree per meter.

The temperatures were recorded with Negretti-Zambra and Richter-Wiese reversing thermometers (equivalent Fahrenheit temperatures are shown in parentheses). These

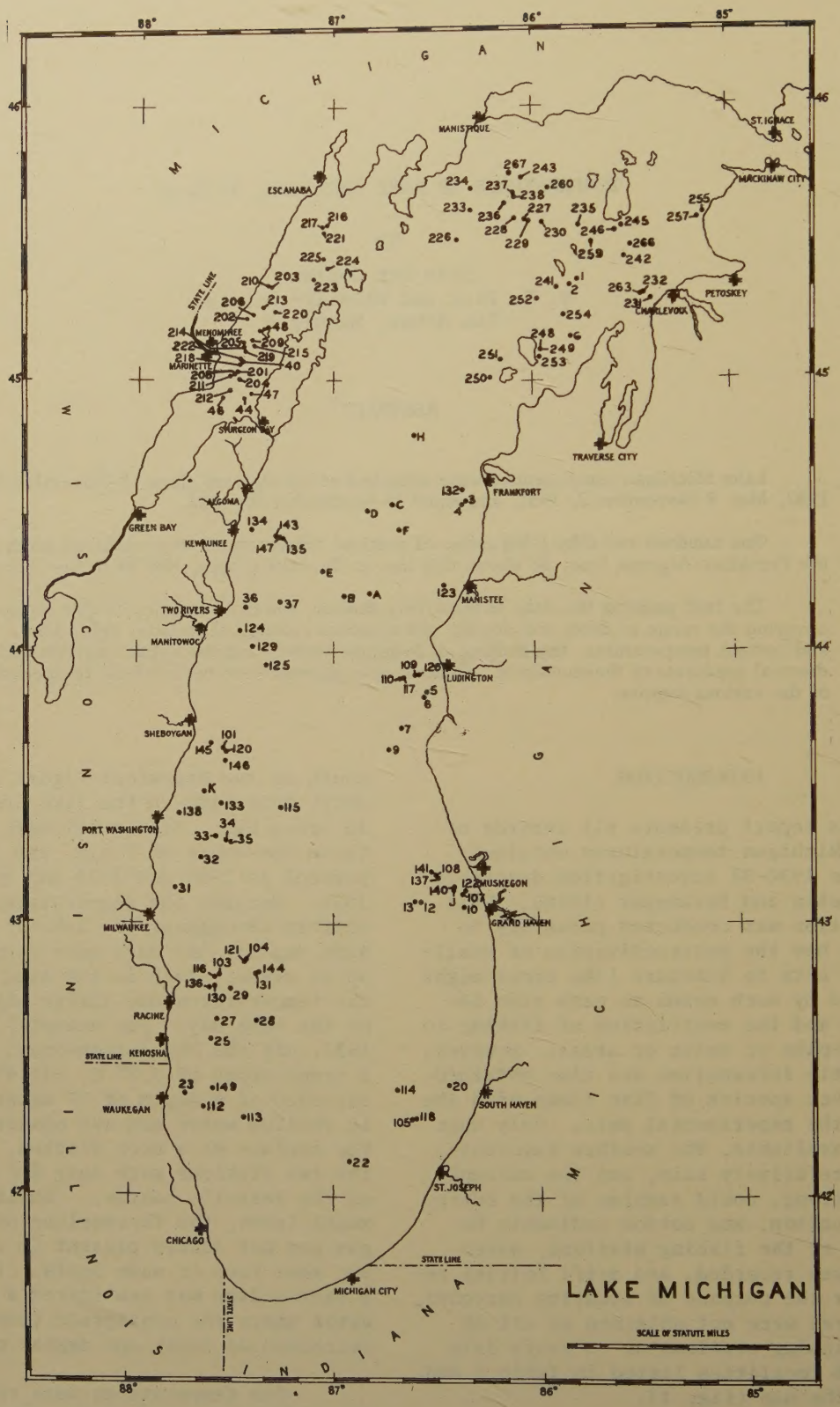


Figure 1. --Map of Lake Michigan, showing stations where temperatures were obtained, 1930-32. Station numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931 and those between 200 and 300 in 1932. Stations A, B, C, D, were occupied in 1931; E, F, G, H in 1932, and J, K in 1930.

Table 1.--Location of Lake Michigan stations where temperatures were obtained. Station numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931 and those between 200 and 300 in 1932. Stations A, B, C, D were occupied in 1931, E, F, G, H in 1932, and J, K in 1930.

| Station No. | Port | Course | Distance (miles) |
|---|---|---|---|
| 1 | Charlevoix, Mich. | W 3/4 N | 25.0 |
| 2 | Charlevoix, Mich. | W 1/2 N | 27.0 |
| 3 | Frankfort, Mich. | SW | 6.5 |
| 4 | Frankfort, Mich. | SW | 8.0 |
| 5 | Ludington, Mich. | SW 7/8 S | 7.5 |
| 6 | Ludington, Mich. | SW 7/8 S | 8.7 |
| 7 | Ludington, Mich. | SW 7/8 S | 18.8 |
| 9 | Ludington, Mich. | SW 7/8 S | 25.3 |
| 10 | Grand Haven, Mich. | W 5/8 N | 5.7 |
| 12 | Grand Haven, Mich. | W 5/8 N | 16.8 |
| 13 | Grand Haven, Mich. | W 5/8 N | 18.0 |
| 20 | South Haven, Mich. | W | 9.2 |
| 22 | St. Joseph, Mich. | W 7/16 N | 22.5 |
| 23 | Waukegan, Ill. | E 3/4 N | 5.0 |
| 25 | Kenosha, Wis. | E | 11.4 |
| 27 | Racine, Wis. | SE x E 3/4 E | 12.0 |
| 28 | Racine, Wis. | ESE 3/4 E | 21.8 |
| 29 | Racine, Wis. | E 7/8 N | 14.6 |
| 31 | Milwaukee, Wis. | NE 1/2 N | 9.0 |
| 32 | Milwaukee, Wis. | NE 1/2 N | 19.0 |
| 33 | Port Washington, Wis. | SE x E 15/16 E | 15.0 |
| 34 | Port Washington, Wis. | SE x E 15/16 E | 18.0 |
| 35 | Port Washington, Wis. | SE x E 15/16 E | 19.0 |
| 36 | Two Rivers, Wis. | E 7/8 N | 5.4 |
| 37 | Two Rivers, Wis. | E 7/8 N | 14.4 |
| 40 | Marinette, Wis. | Green Island (N) | - |
| 44 | Marinette, Wis. | Green Island (SE) | - |
| 46 | Marinette, Wis. | Off Peshtigo Shoal | - |
| 47 | Marinette, Wis. | Green Island (SE) | - |
| 48 | Menominee, Mich. | Chambers Island (W) | - |
| 101 | Sheboygan, Wis. | SE 1/4 E | 10.0 |
| 103 | Racine, Wis. | NE x E 1/2 E | 13.0 |
| 104 | Racine, Wis. | NE x E 1/2 E | 20.5 |
| 105 | St. Joseph, Mich. | NW x N 1/2 N | 14.0 |
| 107 | Grand Haven, Mich. | NW x W | 7.0 |
| 108 | Grand Haven, Mich. | NW x W | 15.0 |
| 109 | Ludington, Mich. | WSW 7/8 W | 7.5 |
| 110 | Ludington, Mich. | WSW 7/8 W | 11.5 |
| 112 | Waukegan, Ill. | ESE 3/4 E | 10.0 |
| 113 | Waukegan, Ill. | ESE 3/4 E | 20.0 |
| 114 | St. Joseph, Mich. | NW x N 1/2 N | 22.2 |
| 115 | Sheboygan, Wis. | SE 1/8 E | 31.7 |
| 116 | Racine, Wis. | NE x E 1/2 E | 11.8 |
| 117 | Ludington, Mich. | WSW 7/8 W | 11.0 |
| 118 | St. Joseph, Mich. | NNW 1/4 W | 13.8 |
| 120 | Sheboygan, Wis. | SE 1/4 E | 11.0 |
| 121 | Racine, Wis. | NE x E 1/2 E | 20.0 |
| 122 | Grand Haven, Mich. | NW 1/8 N | 6.4 |
| 123 | Manistee, Mich. | W 1/2 S | 4.0 |
| 124 | Two Rivers, Wis. | SE 5/8 S | 6.0 |
| 125 | Two Rivers, Wis. | SE 5/8 S | 17.0 |
| 126 | Ludington, Mich. | WSW 7/8 W | 7.0 |
| 129 | Two Rivers, Wis. | SE 5/8 S | 11.0 |
| 130 | Racine, Wis. | E x N 1/2 N | 10.5 |
| 131 | Racine, Wis. | E x N 1/2 N | 21.5 |
| 132 | Frankfort, Mich. | WSW 1/2 S | 4.0 |
| 133 | Port Washington, Wis. | E x N 1/8 N | 16.0 |
| 134 | Kewaunee, Wis. | E x S 1/4 S | 4.0 |
| 135 | Kewaunee, Wis. | E x S 1/4 S | 11.5 |
| 136 | Racine, Wis. | E x N 1/2 N | 9.5 |
| 137 | Grand Haven, Mich. | NW x W | 14.8 |
| 138 | Port Washington, Wis. | E x N 1/8 N | 5.0 |
| 140 | Grand Haven, Mich. | NW 7/8 W | 9.6 |
| 141 | Grand Haven, Mich. | NW 7/8 W | 16.7 |
| 143 | Kewaunee, Wis. | E x S 1/4 S | 10.5 |
| 144 | Racine, Wis. | E x N 1/2 N | 22.5 |
| 145 | Sheboygan, Wis. | SE 1/2 S | 7.5 |
| 146 | Sheboygan, Wis. | SE 1/2 S | 12.7 |
| 147 | Kewaunee, Wis. | E x S 1/4 S | 11.0 |
| 149 | Waukegan, Ill. | E x N | 11.8 |
| 201 | Menominee, Mich. | SE | 7.6 |
| 202 | Menominee, Mich. | NE 1/4 N | 11.0 |
| 203 | Menominee, Mich. | NE 1/2 N | 21.0 |
| 204 | Menominee, Mich. | SE 9/16 S | 9.1 |
| 205 | Menominee, Mich. | ENE 1/4 E | 7.0 |
| 206 | Menominee, Mich. | NE 1/8 N | 13.1 |
| 208 | Menominee, Mich. | SE 9/16 S | 7.0 |
| 209 | Menominee, Mich. | ENE 1/4 E | 9.0 |
| 210 | Menominee, Mich. | NE 5/8 N | 20.9 |
| 211 | Menominee, Mich. | SSE 7/16 E | 7.0 |
| 212 | Menominee, Mich. | S x E 11/16 E | 10.1 |
| 213 | Menominee, Mich. | NE 1/8 E | 16.0 |
| 214 | Menominee, Mich. | E 7/8 N | 7.0 |
| 215 | Menominee, Mich. | E 7/8 N | 9.5 |
| 216 | Escanaba, Mich. | S 1/4 E | 11.5 |
| 217 | Escanaba, Mich. | S 3/16 W | 12.0 |
| 218 | Menominee, Mich. | SE x E 1/2 E | 6.6 |
| 219 | Menominee, Mich. | E 1/16 N | 7.1 |
| 220 | Menominee, Mich. | NE 3/8 E | 17.8 |
| 221 | Escanaba, Mich. | S 1/8 W | 14.0 |
| 222 | Menominee, Mich. | ESE 1/2 E | 6.2 |
| 223 | Escanaba, Mich. | S 1/2 W | 25.5 |
| 224 | Escanaba, Mich. | S 1/8 E | 22.5 |
| 225 | Escanaba, Mich. | S 1/8 W | 20.0 |
| 226 | Manistique, Mich. | S x W 3/16 W | 30.8 |
| 227 | Manistique, Mich. | SSE | 26.5 |
| 228 | Manistique, Mich. | S x E 5/8 E | 25.5 |
| 229 | Manistique, Mich. | SSE 1/8 E | 27.2 |
| 230 | Manistique, Mich. | SSE 5/8 E | 29.1 |
| 231 | Charlevoix, Mich. | W x S | 6.8 |
| 232 | Charlevoix, Mich. | W | 8.2 |
| 233 | Manistique, Mich. | S 3/4 W | 22.8 |
| 234 | Manistique, Mich. | S 7/8 W | 17.0 |
| 235 | Manistique, Mich. | SE 1/4 S | 35.3 |
| 236 | Manistique, Mich. | S x E 1/4 E | 21.0 |
| 237 | Manistique, Mich. | SSE | 19.5 |
| 238 | Manistique, Mich. | SSE | 20.5 |
| 241 | Charlevoix, Mich. | W 5/16 N | 30.5 |
| 242 | Charlevoix, Mich. | NW 7/8 W | 15.8 |
| 243 | Manistique, Mich. | SE x S | 17.2 |
| 245 | Beaver Island Lt., Mich. | SE 7/8 E | 2.5 |
| 246 | Beaver Island Lt., Mich. | S | 2.0 |
| 248 | Leland, Mich. | NW x W | 11.5 |
| 249 | Leland, Mich. | NW x W | 11.5 |
| 250 | Frankfort, Mich. | N 3/8 E | 26.5 |
| 251 | Frankfort, Mich. | N 3/4 E | 31.8 |
| 252 | Charlevoix, Mich. | W 1/8 S | 35.0 |
| 253 | Leland, Mich. | NW x W 3/4 W | 11.2 |
| 254 | Charlevoix, Mich. | W x S | 28.8 |
| 255 | Charlevoix, Mich. | N x E 3/4 E | 21.5 |
| 257 | Charlevoix, Mich. | N x E 1/2 E | 19.2 |
| 259 | Charlevoix, Mich. | NW x W 13/16 W | 24.8 |
| 260 | Manistique, Mich. | SE 1/8 S | 23.6 |
| 263 | Charlevoix, Mich. | W 1/8 S | 8.5 |
| 266 | Charlevoix, Mich. | NW 3/16 N | 16.4 |
| 267 | Manistique, Mich. | SSE 5/16 E | 14.8 |
| A | Manistee, Mich. | W 1/2 S | 25.0 |
| B | Manistee, Mich. | W 1/2 S | 32.0 |
| C | Frankfort, Mich. | WSW 7/8 W | 24.0 |
| D | Frankfort, Mich. | WSW 7/8 W | 30.7 |
| E | Frankfort, Mich. | SW x W 1/2 W | 46.5 |
| F | Frankfort, Mich. | SW x W 1/2 W | 24.7 |
| G | Leland, Mich. | N 15/16 W | 9.4 |
| H | Frankfort, Mich. | NW 7/8 W | 21.0 |
| J | Muskegon, Mich. | SW x S | 7.0 |
| K | Port Washington, Wis. | NE 11/32 E | 13.0 |

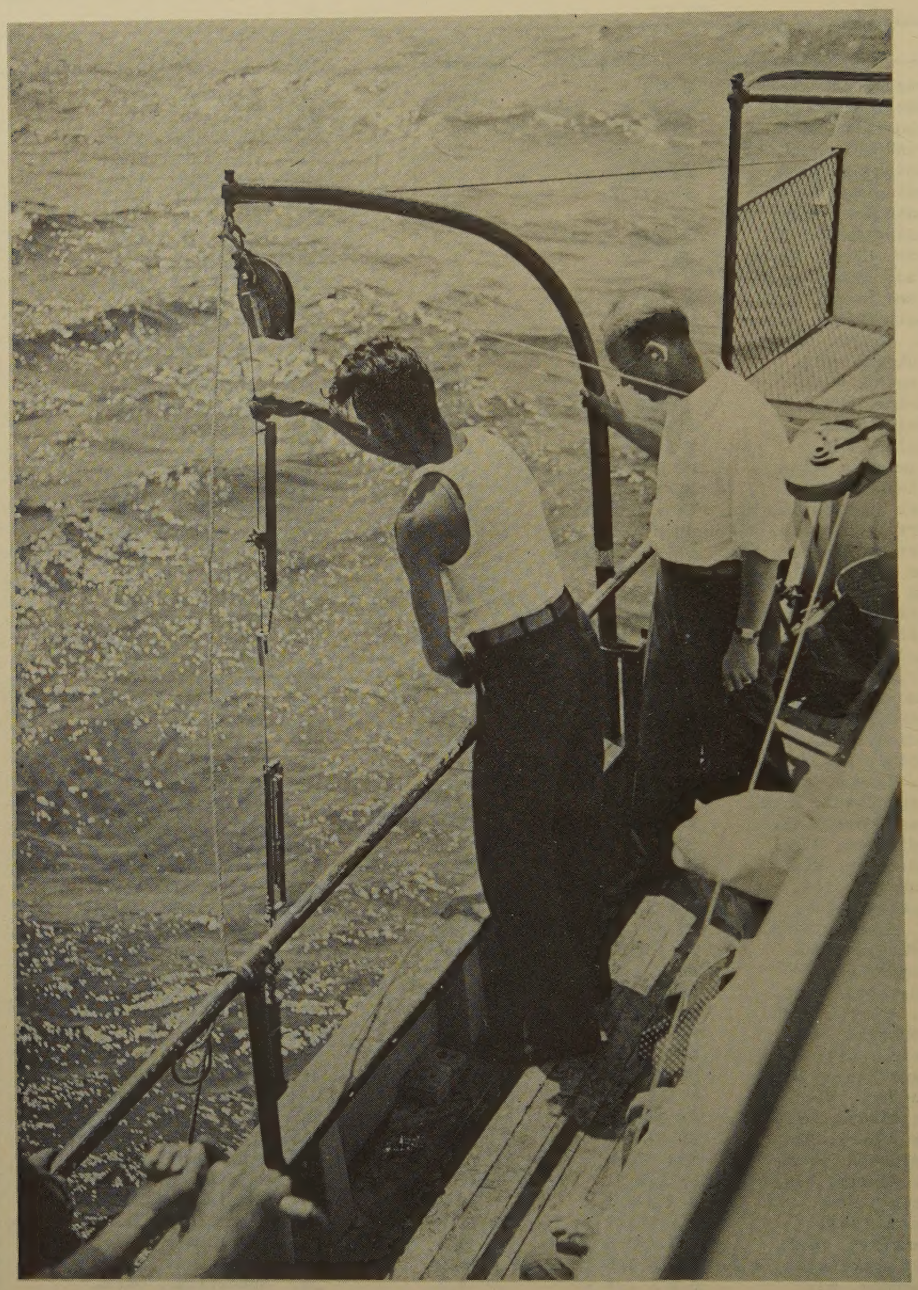

Figure 2.--Shows method employed 1930-32 in taking water temperatures. The cable was attached to the drum of a hand-operated winch, the position of which is indicated by the grasped handle in the lower left corner.

instruments were clamped in a series onto a cable wound on the drum of a hand-operated winch. The cable passed through a meter wheel that recorded the depths at which the several thermometers were reversed. After allowing the last attached thermometer to set for about 5 minutes, a weight was released on the cable that reversed the first thermometer and released its attached weight. Each reversed thermometer, except the last one, released a weight that reversed the next thermometer below (see fig. 2).

No comprehensive survey of the temperatures of Lake Michigan had been made before 1930. Conger (1899) discussed briefly in general terms the July surface temperatures obtained in 1892-94 by masters of vessels plying between the lake ports. Ward (1896) published bottom and surface temperatures obtained August 11-25, 1894, in the northeastern part of the lake. Surface temperatures at various Great Lakes localities were kept during the period 1874-86 by the U. S. Weather Bureau. They were taken daily, except when the lake was frozen, at 2 p.m. from docks where the water was usually 20 feet deep or more. The monthly means of these temperatures were published by Horton and Grunsky (1927) including the ports of Escanaba, Milwaukee, Chicago, and Grand Haven. Koelz (1929) published a few records taken at the surface and bottom during August 14-24 and October 11, 1920, in Green Bay and off the ports of Algoma, Wisconsin, and Michigan City, Indiana. Wright (1931) discussed our low Lake Michigan temperatures (3.8° - 4.0° C.) that were taken in the summer of 1930 at depths beyond 100 meters. He pointed out that pressure lowered the temperature of the water at maximum density.

More extensive and detailed data were obtained after our 1930-32 investigation. Williamson and Greenbank (1940) conducted a survey of the pollution of Green Bay, the lower Fox River, and the East River during the period October 1938 to June 1939 excluding December. Their report included a series of temperatures at a number of Green Bay stations where the depths varied from 3 to 39 feet. Records were obtained at depths of 3 feet, midway to the bottom, and 1 foot above the bottom in water more than 10 feet deep but only at 3 feet in shallower water.

Church (1942, 1945) was the first to publish a comprehensive discussion of the temperatures of Lake Michigan proper that were obtained with a bathythermograph. In his 1942 paper he presented data that were collected largely on a commercial ship route between Milwaukee and Muskegon. Some 270 soundings were taken on 12 round trips on this route during the period November 22, 1941 to March 30, 1942. In addition 71 soundings were made, March 28-April 6, 1942, on a trip from Indiana Harbor to Charlevoix via Milwaukee, Sheboygan, and Frankfort. Data published in his 1945 paper covered the period from March 30 to September 18, 1942. Of the 759 soundings, 438 were made again on the Milwaukee-Muskegon route (March 30-September 13); the others were obtained at a Coast Guard anchor station off Stevensville, Michigan (68 on September 16-18), from a private yacht on the south basin (39 on June 18-20), and from a commercial vessel on routes between Frankfort and Manitowoc, Kewaunee, Menominee, and Manistique (214 on June 7-September 10). His records were not presented in detail in tabular form but only on graphs.

Millar (1952) reported on the temperatures of Lake Michigan recorded by a thermograph installed on the condenser intake set between 15 and 20 feet below the load waterline of a steamship. Records were obtained on the ship's regular route between Chicago and the Straits of Mackinac via Milwaukee. Only monthly grand average temperatures were published for 17 stations covering the periods from May 22 to November 13 in the years 1935 to 1939 and May-July 1941.

Great Lakes temperatures at municipal water sources were compiled by the Michigan Water Resources Commission (1954). The Lake Michigan data were collected either in 1952 or 1953 at the intakes of Menominee, Escanaba, Traverse City, Muskegon, Grand Rapids, and St. Joseph, the depths of which ranged from 12 to 60 feet. The published records were monthly averages, maximum, and minimum.

Griffith (1955) published a curve (no tables) of surface temperatures obtained at Evanston, Illinois at the end of a breakwater where the water was about 2 meters (6.6 ft.) deep. Observations were made with a maximum-minimum thermometer throughout a year from April 1953 to March 1954. Smith (1956) discussed in general terms the position of the thermocline in northern Lake Michigan but presented no

Table 2.--Temperatures C° of Lake Michigan off St. Joseph and South Haven, Michigan, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C5 Sta. 20 Aug. 7 D 52 | | C6 Sta. 20 Aug. 19 D 52 | | C10 Sta. 22 Oct. 23 D 85 | | C2 Sta. 105 May 12 D 55 | | C2 Sta. 114 May 12 D 87 | | C3 Sta. 105 May 27 D 62 | | C3 Sta. 114 May 27 D 85 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air | 23.2 | Air | 16.8 | Air | 8.6 | Air | -- | Air | 11.2 | Air | 17.3 | Air | 15.4 |
| S | 20.9 | S | 20.0 | S | 13.0 | S | 6.5 | S | 5.2 | S | 10.3 | S | 9.1 |
| 5 | 20.6 | 8 | 19.3 | 6 | 13.4 | 2 | 6.2 | 5 | 4.8 | 5 | 9.4 | 5 | 7.6 |
| 10 | 19.9 | 10 | 19.2 | 11 | 13.3 | 7 | 6.1 | 10 | 4.7 | 10 | 9.2 | 10 | 6.5 |
| 15 | 19.3 | 12 | 16.7 | 14 | 13.3 | 12 | 5.9 | 20 | 4.6 | 15 | 8.6 | 20 | 5.7 |
| 18 | 18.0 | 14 | 12.4 | 17 | 13.3 | 17 | 5.6 | 30 | 4.3 | 25 | 8.5 | 30 | 5.5 |
| 220 | 13.8 | 15 | 11.4 | 20 | 13.3 | 27 | 5.5 | 40 | 4.2 | 35 | 6.6 | 40 | 5.3 |
| 22 | 11.0 | 16 | 9.8 | 25 | 13.2 | 37 | 5.2 | 50 | 4.1 | 45 | 4.9 | 50 | 4.7 |
| 24 | 9.2 | 18 | 8.8 | 30 | 13.2 | 55 | 4.3 | 60 | 4.1 | 62 | 4.7 | 60 | 4.5 |
| 27 | 7.7 | 21 | 6.9 | 40 | 13.2 | | | 87 | 4.0 | | | 85 | 4.2 |
| 35 | 5.3 | 24 | 5.7 | 45 | 13.2 | | | | | | | | |
| 52 | 4.7 | 27 | 5.5 | 50 | 11.6 | | | | | | | | |
| | | 30 | 5.5 | 55 | 5.3 | | | | | | | | |
| | | 35 | 5.4 | 60 | 5.1 | | | | | | | | |
| | | 40 | 5.4 | 85 | 4.0 | | | | | | | | |
| | | 52 | 5.3 | | | | | | | | | | |

| C4 Sta. 118 June 9 D 57 | | C4 Sta. 114 June 9 D 94 | | C5 Sta. 118 June 18 D 56 | | C5 Sta. 114 June 18 D 94 | | C6 Sta. 118 July 1 D 53 | | C6 Sta. 114 July 1 D 94 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Air | 15.2 | Air | 15.7 | Air | 18.4 | Air | 21.0 | Air | 24.4 | Air | 26.4 |
| S | 12.2 | S | 9.5 | S | 15.7 | S | 15.6 | S | 22.6 | S | 23.1 |
| 5 | 12.0 | 8 | 8.8 | 5 | 15.0 | 5 | 13.8 | 5 | 20.8 | 4 | 19.7 |
| 10 | 12.0 | 18 | 7.4 | 10 | 12.4 | 10 | 10.8 | 8 | 18.2 | 7 | 17.6 |
| 15 | 11.9 | 23 | 6.0 | 15 | 11.0 | 15 | 8.9 | 10 | 15.8 | 8 | 15.5 |
| 20 | 11.8 | 29 | 5.6 | 20 | 9.3 | 20 | 8.2 | 12 | 11.8 | 9 | 14.0 |
| 30 | 11.8 | 32 | 5.5 | 25 | 7.2 | 25 | 5.8 | 14 | 10.8 | 10 | 12.5 |
| 33 | 6.7 | 35 | 5.3 | 30 | 6.5 | 35 | 5.2 | 16 | 10.1 | 12 | 11.0 |
| 35 | 6.2 | 40 | 5.0 | 35 | 6.0 | 45 | 4.8 | 18 | 9.3 | 14 | 10.0 |
| 40 | 5.6 | 50 | 4.3 | 40 | 5.6 | 55 | 4.6 | 20 | 8.8 | 16 | 9.5 |
| 57 | 4.5 | 60 | 4.2 | 45 | 4.9 | 65 | 4.4 | 25 | 6.9 | 18 | 8.6 |
| | | 94 | 4.0 | 56 | 4.6 | 80 | 4.1 | 30 | 5.3 | 20 | 7.4 |
| | | | | | | 94 | 4.0 | 35 | 4.9 | 25 | 5.8 |
| | | | | | | | | 40 | 4.9 | 35 | 5.6 |
| | | | | | | | | 53 | 4.8 | 45 | 4.9 |
| | | | | | | | | | | 55 | 4.7 |
| | | | | | | | | | | 65 | 4.4 |
| | | | | | | | | | | 80 | 4.2 |
| | | | | | | | | | | 94 | 4.2 |

specific data. The cruises were made in 1955. Lauff (1957) published surface and subsurface temperatures obtained at 30 stations in Grand Traverse Bay on July 30 and 31, 1954.

Ayers et al. (1958) presented in detail the limnological data (transparencies, temperatures, chemicals, currents) collected at 174 Lake Michigan stations by the synoptic survey method (multiple-boat single-date coverage of entire lake). The 4 synoptic cruises covered 8 pair of round trips across the lake on June 28 and 29 and 7 pair on August 9 and 10, 1955. The authors discussed the results of each synoptic cruise. Two hundred and forty-two (242) temperature soundings were taken from a bathythermograph and checked by a reversing thermometer. The discussion usually covered the range, average, maximum, and minimum of the surface temperatures of the major sections and the isotherms that were also mapped throughout the lake. Vertical temperatures were also shown on charts. The text emphasized the details of the thermoclines (sharp thermal gradients, discontinuity layers) but also contained discussions of the isotherms of the epilimnion and hypolimnion and the temperatures of the bottom.

## STATIONS OFF ST. JOSEPH-SOUTH HAVEN

Thirteen (13) series of temperatures were taken off St. Joseph and South Haven in 1930 and 1931 (table 2). Depths of the 3 designated shallow stations ranged from 52 to 62 meters (171 to 203 ft.) and of the 2 deep stations from 85 to 94 meters (279 to 308 ft.) and averaged 55 and 90 meters (180 and 295 ft.) respectively.

In 1931 the surface temperatures of both deep and shallow waters increased progressively from about 5° to 6° (41° to 43° F.) on May 12 to 23° (73° F.) on July 1. The 1930 records were 20° and 20.9° (68° and 69.6° F.) in August and 13° (55° F.) in October. Although the deep-station surface temperatures were comparatively low until June 9, they later rose rapidly and finally exceeded the shallow-water surface temperature.

The subsurface temperatures of both years followed at various depths the trend of the surface temperatures. They had increased at all levels on May 27, 1931, but thereafter only down to a maximum of 30 meters (98 ft.), although on June 18 and July 1, 1931, and August 19, 1930, upwellings had brought cold water to upper levels as high as 10 to 15 meters (33 to 49 ft.) but only at the shallow stations. When the temperatures of the upper levels changed, those below shifted in the opposite direction, remained constant, or fluctuated at different depths. The subsurface waters warmed most rapidly at the shallow stations, and on the same dates their temperatures were almost always higher than those of the corresponding levels of the deep areas.

Five-degree (41° F.) water was confined almost entirely to depths of 40-45 meters (131-148 ft.) during May-August, except at certain deep stations when it occurred above 5 meters (16 ft.) on May 12. and below 60 meters (197 ft.) on October 23. In 1931 the bottom temperature rose slightly in the shallow waters from 4.3° to 4.7° (39.7° to 40.5° F.) in May and then remained practically constant through July 1. In August 1930 it increased from 4.7° on the 7th to 5.3° on the 19th (40.5° to 41.5° F.). In the deep waters the bottom temperatures of both years ranged only from 4.0° to 4.2° (39.2° to 39.6° F.).

The earliest thermocline was observed in the shallow water on June 9, 1931, at depths of 30-33 meters (98-108 ft.), but none had formed at the deep station. By June 18 the cold water had risen and wiped out this thermocline. On July 1 a thermocline was again recorded but this time at both deep and shallow stations at approximately the same level and temperatures. An upwelling had also shifted a thermocline to shallower water in August 1930. Because of such movements the subsurface temperatures above the bottom did not always increase at all depths with the advance of the season. In the fall the temperatures begin to approach uniformity at all depths. This fact was evidenced by the October 23 records when the temperatures were virtually uniform down to at least 45 meters (148 ft.), and a thermocline had formed between 50 and 55 meters (164 and 180 ft.).

The depth intervals covered by the thermoclines ranged from 3 to 6 meters (10 to 20 ft.) and averaged 4 meters (13 ft.). Their thermal gradients varied from 5° to 9° (9° to 16° F.) and averaged 7° (12° F.).

Table 3.--Temperatures C° of Lake Michigan off Grand Haven and Muskegon, Michigan, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C1 Sta. J June 19 D 74 Air -- | C1 Sta. 10 June 20 D 65 Air 17.2 | C1 Sta. 12 June 20 D 102 Air -- | C2 Sta. 10 June 30 D 60 Air 16.0 | C3 Sta. 10 July 11 D 48 Air 19.4 | C3 Sta. 13 July 11 D 102 Air 20.0 | C4 Sta. 10 July 25 D 45 Air 19.0 | C4 Sta. 13 July 25 D 102 Air 23.0 |
|---|---|---|---|---|---|---|---|
| S 12.7 | S 13.0 | S 8.1 | S 13.4 | S 16.6 | S 16.2 | S 17.8 | S 17.5 |
| 2 12.2 | 9 11.4 | 4 7.3 | 5 13.2 | 3 16.2 | 4 15.2 | 5 17.0 | 6 16.0 |
| 7 11.9 | 12 11.3 | 7 7.0 | 9 13.0 | 8 13.0 | 7 12.5 | 10 16.1 | 12 14.7 |
| 12 7.5 | 15 11.0 | 12 6.5 | 13 12.4 | 11 11.3 | 10 11.5 | 12 12.3 | 15 14.0 |
| 17 6.5 | 18 10.6 | 17 6.4 | 17 9.2 | 14 10.2 | 13 10.7 | 13 10.3 | 18 11.1 |
| 22 6.2 | 21 9.9 | 22 6.4 | 20 7.7 | 17 8.4 | 16 10.2 | 15 8.1 | 21 9.8 |
| 32 5.6 | 24 9.4 | 27 5.9 | 25 7.0 | 23 5.9 | 26 7.4 | 16 6.5 | 25 7.7 |
| 42 5.0 | 27 6.0 | 32 5.3 | 35 4.5 | 30 5.0 | 52 4.4 | 19 5.8 | 45 4.5 |
| 74 4.0 | 30 5.6 | 62 4.2 | 60 ? | 48 4.4 | 102 4.0 | 23 5.4 | 102 4.0 |
| | 35 5.4 | 102 3.9 | | | | 30 5.0 | |
| | 65 4.2 | | | | | 45 4.0 | |

| C5 Sta. 10 Aug. 6 D 49 Air 22.5 | C5 Sta. 13 Aug. 6 D 102 Air 25.1 | C6 Sta. 13 Aug. 18 D 101 Air 18.0 | C2 Sta. 107 May 14 D 52 Air 11.8 | C2 Sta. 108 May 14 D 94 Air 13.8 | C5 Sta. 108 June 22 D 99 Air 19.4 | C6 Sta. 108 July 2 D 94 Air 25.0 | C7 Sta. 122 July 18 D 44 Air 25.7 |
|---|---|---|---|---|---|---|---|
| S 19.9 | S 20.5 | S 19.2 | S 5.3 | S 5.2 | S 13.6 | S 19.1 | S 20.6 |
| 5 19.4 | 6 19.4 | 8 19.6 | 5 4.7 | 1 4.7 | 5 12.5 | 4 19.1 | 3 20.6 |
| 10 18.9 | 12 17.8 | 15 19.3 | 10 4.3 | 6 3.8 | 10 9.0 | 7 17.0 | 6 20.5 |
| 13 18.6 | 18 14.4 | 17 16.2 | 15 4.1 | 16 3.8 | 15 7.9 | 9 14.6 | 8 19.1 |
| 15 18.5 | 21 10.6 | 19 13.0 | 20 4.0 | 26 3.8 | 22 7.2 | 11 14.0 | 10 18.2 |
| 17 17.2 | 24 9.4 | 21 12.2 | 30 4.0 | 36 3.8 | 30 6.0 | 13 12.4 | 12 13.4 |
| 19 12.6 | 27 8.2 | 24 11.1 | 40 4.0 | 51 3.8 | 40 5.0 | 15 12.0 | 14 11.2 |
| 22 8.3 | 30 7.2 | 27 9.8 | 52 4.0 | 66 3.8 | 55 4.3 | 17 9.8 | 16 8.6 |
| 25 6.7 | 40 5.1 | 30 8.1 | | 94 3.8 | 70 4.0 | 18 9.4 | 18 6.3 |
| 32 5.1 | 50 4.2 | 35 5.7 | | | 85 4.0 | 20 8.2 | 20 5.8 |
| 49 4.6 | 102 4.1 | 50 4.3 | | | 99 3.9 | 25 7.4 | 25 4.9 |
| | | 101 4.1 | | | | 35 5.3 | 30 4.6 |
| | | | | | | 45 4.4 | 44 4.5 |
| | | | | | | 60 4.3 | |
| | | | | | | 75 4.0 | |
| | | | | | | 94 4.0 | |

| C7 Sta. 108 July 18 D 95 Air 24.2 | C9 Sta. 122 Aug. 7 D 44 Air 24.0 | C10 Sta. 122 Aug. 17 D 40 Air 20.3 | C10 Sta. 137 Aug. 17 D 107 Air 22.3 | C12 Sta. 141 Sept. 3 D 108 Air 19.0 | C14 Sta. 140 Sept. 29 D 63 Air 18.5 | C14 Sta. 141 Sept. 29 D 107 Air 19.3 |
|---|---|---|---|---|---|---|
| S 21.6 | S 22.7 | S 14.5 | S 21.3 | S 18.6 | S 17.3 | S 17.0 |
| 4 21.2 | 11 22.3 | 5 10.4 | 5 17.8 | 5 18.2 | 5 17.3 | 5 17.0 |
| 7 19.3 | 13 22.2 | 7 9.5 | 8 14.0 | 9 18.2 | 10 17.3 | 10 17.0 |
| 10 14.6 | 15 19.6 | 10 8.2 | 10 12.3 | 12 16.2 | 15 16.6 | 15 16.9 |
| 12 9.6 | 17 11.7 | 11 7.0 | 12 11.0 | 15 15.8 | 18 15.9 | 18 16.9 |
| 14 7.5 | 20 7.9 | 13 5.9 | 15 10.7 | 17 15.6 | 21 11.3 | 21 16.9 |
| 16 7.0 | 24 5.5 | 16 5.6 | 20 8.0 | 19 15.4 | 24 6.4 | 24 14.3 |
| 18 6.6 | 34 4.3 | 19 5.5 | 30 5.9 | 21 14.9 | 30 4.8 | 25 9.2 |
| 20 6.2 | 44 4.2 | 22 5.4 | 40 5.2 | 23 12.6 | 35 4.4 | 27 6.6 |
| 25 5.6 | | 25 5.2 | 50 4.2 | 25 7.5 | 40 4.2 | 30 4.4 |
| 35 4.9 | | 30 5.2 | 60 4.0 | 30 6.0 | 63 4.1 | 40 4.2 |
| 45 4.2 | | 40 5.2 | 80 4.0 | 35 5.5 | | 55 4.2 |
| 60 4.0 | | | 107 4.0 | 45 4.5 | | 80 4.2 |
| 75 4.0 | | | | 60 4.2 | | 107 4.1 |
| 95 4.0 | | | | 80 4.2 | | |
| | | | | 108 4.2 | | |

## STATIONS OFF GRAND HAVEN-MUSKEGON

Temperatures were collected on 15 days off the Grand Haven-Muskegon shore (table 3) during June 19-August 18, 1930, and May 14-September 29, 1931, at 5 shallow stations with depths 40-74 meters (131-243 ft.) and at 5 deep stations with depths 94-108 meters (308-354 ft.). These depths averaged 53 and 101 meters (174 and 331 ft.).

The surface temperatures of the waters during both years rose progressively from the first dates of observation throughout the summer usually reaching the maximum during the first week of August. The temperatures reached 20° (68° F.) in 1930 and nearly 23° (73° F.) in 1931. Although the surface temperatures were at first lower at the deep than at the shallow stations, they rose higher in deep water late July or early August. However, an upwelling had reduced the shallow-water temperature sharply to 14.5° (58.1° F.) on August 17, 1931, 6.8° (12.2° F.) below the deep-water temperature. The surface waters were warmer in 1931 than in 1930 during the summer months.

In both years the subsurface temperatures of the shallow stations followed the trend of the surface temperatures either to the bottom or down to levels that fluctuated between 3 and about 25 meters (10 and 82 ft.). The reversal of the temperatures below these different levels had continued to the bottom. In deep water the subsurface temperatures had also followed the directions of change of the surface temperatures, except on September 3, 1931, either to the bottom or down to at least 50 meters (164 ft.) in 1930 and to 10-25 meters (33-82 ft.) in 1931, below which the reversed temperatures either remained constant or increased and decreased at the different levels.

The subsurface temperatures of the deep stations gradually approached those of the shallow stations and as the season advanced the former at times exceeded the latter at various levels. Upwellings had shifted the relationship when in 1931 cold water had risen to at least a 12-meter (39 ft.) level on July 18 at the deep station and to the surface on August 17 at the shallow station, an unusual occurrence.

Five-degree (41° F.) water was still found above the 5-meter (16 ft.) level on May 14, 1931, at both stations. During the period from the middle of June to the end of September this temperature had been lowered in both years to depths that usually varied from about 25 to 35 meters (82 to 115 ft.) in the shallow water and 30 to 45 meters (98 to 148 ft.) in the deep water. Temperatures below 4.0° (39.2° F.) were recorded in May and June but only at the deep-water stations. On May 14, 1931, a temperature of 3.8° (38.8° F.) was recorded from the 6-meter (20 ft.) level to the bottom. Bottom temperatures of 3.9° (39.0° F.) were recorded on June 20, 1930, and 22, 1931, but thereafter they varied from 4.0° (39.2° F.) to 4.2° (39.6° F.) in deep water reaching the maximum in August 1930 and early September 1931. The shallow-water bottom temperatures fluctuated from 4.0° (39.2° F.) to 4.6° (40.3° F.) in 1930 and 5.2° (41.4° F.) in 1931 during May-September, reaching the maximum in August of both years.

The earliest recorded thermocline appeared in 1930 on June 20 but only at the shallow station at depths of 24 to 27 meters (79 to 89 ft.). Later it was eliminated but then again recorded on July 25 in depths of only 10-16 meters (33-52 ft.). Technically no thermocline formed at the deep station on this date but the difference of the temperatures at 15 and 18 meters (49 and 59 ft.) was 2.9° (5.2° F.). In August a thermocline occurred in both waters at nearly the same level between depths of 15 and 22 meters (49 and 72 ft.).

In 1931 the thermocline was first recorded on July 2 at two levels of a deep-water station. It persisted thereafter in both waters on all dates of observations to September 29. During the summer it had fluctuated between depths of 10 and 20 meters (33 and 66 ft.) in the shallow water and between depths of 5 and 17 meters (16 and 56 ft.) in the deep water. In the fall the thermoclines of both waters had descended to depths between 18 and 27 meters (59 and 89 ft.).

The depth intervals covered by the thermoclines generally ranged from 3 to 8 meters (10 to 26 ft.) and averaged 4 meters (13 ft.) in each year. The thermocline thermal gradients averaged 7° (13° F.) in the shallow waters in 1930 and in both waters in 1931 but averaged only 4° (7° F.) in the deep waters in 1930.

Table 4.--Temperatures C° of Lake Michigan off Ludington, Manistee, and Frankfort, Michigan, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C1 Sta. 4 June 18 D 150 | | C1 Sta. 3 June 18 D 58 | | C2 Sta. 3 June 27 D 58 | | C2 Sta. 4 June 27 D 168 | | C2 Sta. 6 June 28 D 57 | | C2 Sta. 9 June 28 D 125 | | C3 Sta. 3 July 8 D 57 | | C3 Sta. 4 July 8 D 156 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air | -- | Air | -- | Air | 17.2 | Air | 15.0 | Air | 12.0 | Air | 15.0 | Air | 18.6 | Air | 20.4 |
| S | 7.4 | S | 8.7 | S | 14.1 | S | 8.9 | S | 12.3 | S | 11.8 | S | 12.2 | S | 11.8 |
| 8 | 7.0 | 3 | 8.3 | 3 | 12.8 | 3 | 7.8 | 3 | 12.0 | 5 | 11.5 | 5 | 8.8 | 5 | 8.0 |
| 18 | 4.6 | 8 | 8.0 | 7 | 11.8 | 8 | 6.3 | 6 | 11.8 | 9 | 8.3 | 9 | 8.4 | 9 | 7.1 |
| 28 | 4.3 | 13 | 5.6 | 10 | 9.3 | 13 | 5.0 | 9 | 11.7 | 12 | 8.2 | 12 | 7.8 | 12 | 6.5 |
| 38 | 4.2 | 18 | 5.2 | 13 | 8.3 | 18 | 4.5 | 12 | 11.1 | 17 | 7.6 | 15 | 7.2 | 15 | 6.1 |
| 50 | 4.2 | 30 | 5.0 | 18 | 7.7 | 28 | 4.5 | 15 | 9.4 | 25 | 5.8 | 20 | 6.9 | 20 | 5.8 |
| 58 | 4.2 | 58 | ? | 23 | 7.1 | 38 | 4.3 | 17 | 8.9 | 45 | 4.3 | 30 | 5.8 | 40 | 4.8 |
| 68 | 4.2 | | | 28 | 6.5 | 88 | 4.0 | 22 | 6.1 | 75 | 4.0 | 40 | 4.4 | 86 | 4.1 |
| 88 | 4.2 | | | 48 | 5.2 | 168 | 3.9 | 27 | 5.3 | 125 | 3.9 | 57 | 4.1 | 156 | 4.0 |
| 98 | 4.2 | | | 58 | 4.6 | | | 37 | 4.5 | | | | | | |
| 108 | 4.2 | | | | | | | 57 | 4.2 | | | | | | |
| 118 | 4.2 | | | | | | | | | | | | | | |
| 128 | 4.1 | | | | | | | | | | | | | | |
| 150 | 4.0 | | | | | | | | | | | | | | |

| C3 Sta. 5 July 10 D 53 | | C3 Sta. 7 July 10 D 96 | | C4 Sta. 5 July 23 D 52 | | C4 Sta. 9 July 23 D 114 | | C5 Sta. 4 Aug. 1 D 166 | | C5 Sta. 5 Aug. 5 D 51 | | C5 Sta. 9 Aug. 5 D 113 | | C2 Sta. 109 May 15 D 63 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air | 18.6 | Air | 19.5 | Air | 16.9 | Air | 18.8 | Air | 20.9 | Air | 23.5 | Air | 27.3 | Air | 13.4 |
| S | 14.2 | S | 13.7 | S | 13.3 | S | 14.9 | S | 17.5 | S | 19.9 | S | 20.0 | S | 4.1 |
| 5 | 10.6 | 5 | 12.5 | 5 | 12.5 | 6 | 13.6 | 4 | 17.3 | 5 | 19.2 | 6 | 19.0 | 5 | 4.0 |
| 10 | 9.8 | 9 | 11.5 | 10 | 12.0 | 11 | 13.4 | 9 | 13.4 | 10 | 19.0 | 12 | 19.0 | 10 | 4.0 |
| 13 | 9.2 | 12 | 8.9 | 13 | 9.5 | 14 | 10.6 | 12 | 12.6 | 13 | 18.8 | 15 | 19.0 | 15 | 3.9 |
| 16 | 8.7 | 16 | 7.7 | 16 | 8.3 | 17 | 9.5 | 15 | 12.2 | 15 | 18.5 | 18 | 18.5 | 20 | 3.8 |
| 19 | 8.1 | 20 | 7.4 | 19 | 7.8 | 20 | 8.1 | 18 | 11.0 | 17 | 17.0 | 20 | 18.1 | 30 | 3.8 |
| 25 | 6.4 | 30 | 5.8 | 23 | 6.9 | 24 | 6.8 | 23 | 8.9 | 20 | 10.0 | 22 | 17.0 | 40 | 3.8 |
| 30 | 5.0 | 55 | 4.0 | 33 | 4.5 | 46 | 4.6 | 48 | 4.8 | 25 | 7.8 | 26 | 13.9 | 63 | 3.8 |
| 53 | 4.3 | 96 | 3.9 | 52 | 4.3 | 114 | 4.0 | 166 | 4.0 | 30 | 6.4 | 34 | 7.2 | | |
| | | | | | | | | | | 37 | 5.0 | 53 | 4.4 | | |
| | | | | | | | | | | 51 | 4.0 | 113 | 4.0 | | |

| C2 Sta. 110 May 19 D 135 | | C3 Sta. 117 May 29 D 145 | | C4 Sta. 109 June 11 D 63 | | C4 Sta. 117 June 11 D 143 | | C5 Sta. 117 June 23 D 103 | | C5 Sta. 123 June 24 D 119 | | C5 Sta. A June 24 D 220 | | C6 Sta. 126 July 3 D 53 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air | 10.7 | Air | 11.0 | Air | 13.8 | Air | 14.2 | Air | 18.0 | Air | 17.3 | Air | 19.0 | Air | 19.4 |
| S | 4.0 | S | 4.8 | S | 7.5 | S | 6.6 | S | 12.7 | S | 12.9 | S | 13.2 | S | 19.2 |
| 10 | 3.8 | 5 | 4.3 | 5 | 6.5 | 5 | 6.1 | 5 | 11.6 | 5 | 12.4 | 5 | 11.8 | 4 | 18.9 |
| 15 | 3.8 | 15 | 4.2 | 10 | 6.4 | 10 | 6.0 | 10 | 11.6 | 10 | 11.7 | 10 | 10.3 1/ | 7 | 16.6 |
| 25 | 3.8 | 25 | 4.2 | 15 | 6.4 | 15 | 6.0 | 11 | 10.1 | 15 | 9.8 | 15 | 6.3 | 10 | 13.9 |
| 40 | 3.8 | 40 | 4.1 | 20 | 5.8 | 25 | 5.8 | 12 | 8.9 | 20 | 8.5 | 20 | 5.4 | 12 | 13.0 |
| 60 | 3.8 | 65 | 3.9 | 25 | 5.0 | 35 | 4.7 | 13 | 8.3 | 25 | 8.1 | 25 | 5.0 | 14 | 12.0 |
| 80 | 3.8 | 90 | 3.8 | 30 | 4.6 | 45 | 4.4 | 14 | 7.5 | 35 | 6.9 | 30 | 4.8 | 16 | 10.6 |
| 110 | 3.8 | 115 | 3.8 | 35 | 4.2 | 60 | 3.9 | 15 | 7.1 | 45 | 5.5 | 40 | 4.4 | 18 | 8.7 |
| 135 | 3.8 | 145 | 3.8 | 40 | 4.0 | 75 | 3.8 | 25 | 5.4 | 55 | 4.4 | 50 | 4.3 | 20 | 7.4 |
| | | | | 50 | 4.0 | 100 | 3.8 | 35 | 4.8 | 70 | 4.2 | 65 | 4.1 | 25 | 5.0 |
| | | | | 63 | 3.9 | 143 | 3.8 | 50 | 4.2 | 85 | 3.9 | 80 | 4.0 | 30 | 4.3 |
| | | | | | | | | 65 | 3.9 | 100 | 3.9 | 95 | 3.9 | 40 | 4.1 |
| | | | | | | | | 80 | 3.9 | 119 | 3.9 | 110 | 3.9 | 53 | 4.0 |
| | | | | | | | | 95 | 3.9 | | | 125 | 3.8 | | |
| | | | | | | | | 103 | 3.9 | | | 150 | 3.6 | | |
| | | | | | | | | | | | | 175 | 3.6 | | |
| | | | | | | | | | | | | 200 | 3.6 | | |
| | | | | | | | | | | | | 220 | 3.6 | | |

1/ Probably a thermocline between 10 and 15.

Table 4.—Temperature C° of Lake Michigan off Ludington, Manistee, and Frankfort, Michigan, 1930 and 1931. Cont'd.

| C6 Sta. 123 July 6 D 89 Air 20.3 | | C6 Sta. B July 7 D 220 Air 21.4 | | C7 Sta. 126 July 20 D 54 Air 24.2 | | C7 Sta. 117 July 20 D 100 Air 22.6 | | C7 Sta. 132 July 22 2/ D 189 Air 20.8 | | C8 Sta. 132 July 30 3/ D 47 Air 21.8 | | C8 Sta. C July 30 D 244 Air 22.3 | | C10 Sta. 126 Aug. 18 D 52 Air 22.0 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 17.2 | S | 16.6 | S | 21.2 | S | 21.3 | S | 20.3 | S | 21.6 | S | 19.4 | S | 19.9 |
| 5 | 16.8 | 4 | 16.1 | 4 | 21.1 | 4 | 21.3 | 5 | 20.3 | 5 | 21.6 | 5 | 19.1 | 6 | 19.5 |
| 8 | 15.8 | 7 | 16.0 | 7 | 21.0 | 5 | 21.1 | 8 | 20.0 | 8 | 21.6 | 8 | 19.0 | 9 | 18.2 |
| 10 | 15.6 | 10 | 13.0 | 10 | 19.2 | 7 | 20.6 | 11 | 19.0 | 10 | 21.5 | 10 | 19.0 | 11 | 13.8 |
| 12 | 15.5 | 12 | 10.6 | 12 | 18.4 | 10 | 18.1 | 14 | 16.1 | 12 | 21.3 | 12 | 18.9 | 13 | 10.1 |
| 14 | 15.3 | 14 | 9.6 | 14 | 16.8 | 12 | 14.1 | 17 | 10.5 | 14 | 21.0 | 14 | 18.2 | 15 | 8.8 |
| 16 | 12.8 | 16 | 8.5 | 16 | 13.6 | 14 | 9.4 | 20 | 8.0 | 16 | 20.8 | 16 | 14.0 | 17 | 7.2 |
| 18 | 10.6 | 18 | 7.7 | 18 | 11.4 | 16 | 8.2 | 25 | 6.6 | 18 | 19.6 | 18 | 11.2 | 20 | 6.2 |
| 20 | 8.7 | 20 | 6.8 | 20 | 9.8 | 18 | 7.1 | 30 | 5.9 | 20 | 13.5 | 20 | 8.7 | 25 | 4.6 |
| 25 | 8.0 | 25 | 5.4 | 25 | 6.7 | 20 | 6.4 | 40 | 5.0 | 23 | 9.8 | 22 | 7.8 | 30 | 4.4 |
| 35 | 6.6 | 30 | 4.8 | 30 | 5.2 | 25 | 5.6 | 60 | 4.5 | 25 | 6.2 | 25 | 6.8 | 40 | 4.1 |
| 45 | 4.5 | 40 | 4.4 | 40 | 4.1 | 35 | 4.6 | 80 | 4.2 | 30 | 4.8 | 30 | 6.2 | 52 | 4.1 |
| 55 | 4.2 | 50 | 4.3 | 54 | 4.0 | 45 | 4.2 | 100 | 3.9 | 40 | 4.1 | 40 | 4.8 | | |
| 70 | 4.0 | 60 | 4.1 | | | 60 | 4.0 | 125 | 3.8 | 47 | 3.9 | 50 | 4.4 | | |
| 89 | 4.0 | 75 | 4.0 | | | 75 | 3.9 | 150 | 3.8 | | | 60 | 4.3 | | |
| | | 100 | 4.0 | | | 90 | 3.9 | 189 | 3.8 | | | 80 | 4.1 | | |
| | | 125 | 4.0 | | | 100 | 3.9 | | | | | 100 | 4.0 | | |
| | | 150 | 3.7 | | | | | | | | | 125 | 3.9 | | |
| | | 175 | 3.6 | | | | | | | | | 150 | 3.8 | | |
| | | 200 | 3.6 | | | | | | | | | 175 | 3.7 | | |
| | | 220 | 3.6 | | | | | | | | | 200 | 3.6 | | |
| | | | | | | | | | | | | 225 | 3.6 | | |
| | | | | | | | | | | | | 244 | 3.6 | | |

| C10 Sta. 117 Aug. 18 D 98 Air 23.3 | | C10 Sta. 132 Aug. 19 D 58 Air 21.5 | | C11 Sta. 126 Aug. 26 D 53 Air 14.5 | | C11 Sta. 117 Aug. 26 D 91 Air 16.2 | | C11 Sta. 132 Aug. 27 D 59 Air 16.4 | | C11 Sta. D Aug. 27 D 250 Air 20.1 | | C12 Sta. 117 Sept. 4 D 108 Air 19.8 | | C13 Sta. 109 Sept. 18 D 62 Air 17.6 | | C13 Sta. 117 Sept. 18 D 116 Air 17.9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 21.5 | S | 19.7 | S | 13.0 | S | 14.4 | S | 12.8 | S | 20.2 | S | 17.1 | S | 19.0 | S | 19.4 |
| 6 | 17.0 | 5 | 19.6 | 3 | 12.9 | 4 | 14.4 | 4 | 12.8 | 5 | 20.1 | 5 | 17.0 | 5 | 19.0 | 5 | 19.4 |
| 11 | 11.0 | 8 | 13.4 | 6 | 12.9 | 7 | 14.3 | 6 | 12.8 | 10 | 20.1 | 9 | 17.0 | 10 | 19.0 | 10 | 19.4 |
| 13 | 10.2 | 11 | 6.5 | 9 | 11.4 | 10 | 14.0 | 8 | 12.4 | 13 | 20.1 | 12 | 17.0 | 16 | 19.0 | 13 | 19.2 |
| 15 | 10.2 | 13 | 5.7 | 11 | 11.2 | 12 | 11.0 | 10 | 10.6 | 15 | 20.0 | 15 | 15.2 | 19 | 18.8 | 15 | 19.2 |
| 20 | 10.0 | 15 | 5.6 | 13 | 10.4 | 14 | 8.5 | 12 | 7.7 | 17 | 20.0 | 17 | 12.9 | 21 | 17.8 | 17 | 18.0 |
| 25 | 8.0 | 20 | 5.0 | 15 | 9.6 | 16 | 7.1 | 14 | 6.8 | 20 | 20.0 | 19 | 12.8 | 23 | 12.5 | 19 | 10.2 |
| 35 | 6.8 | 25 | 4.8 | 17 | 7.4 | 18 | 6.3 | 16 | 5.8 | 21 | 19.9 | 21 | 9.7 | 25 | 9.2 | 21 | 8.9 |
| 45 | 5.3 | 30 | 4.5 | 20 | 6.2 | 20 | 5.6 | 18 | 5.2 | 23 | 14.2 | 23 | 6.2 | 27 | 5.9 | 23 | 7.7 |
| 60 | 4.4 | 40 | 4.2 | 25 | 5.2 | 25 | 5.4 | 20 | 5.0 | 25 | 11.0 | 25 | 5.4 | 30 | 5.2 | 25 | 6.8 |
| 75 | 4.2 | 50 | 4.2 | 30 | 5.0 | 30 | 4.6 | 25 | 4.5 | 28 | 6.8 | 30 | 5.0 | 40 | 4.3 | 27 | 5.8 |
| 90 | 4.0 | 58 | 4.2 | 53 | 4.5 | 40 | 4.2 | 30 | 4.2 | 30 | 6.6 | 40 | 4.3 | 62 | 4.0 | 30 | 5.2 |
| 98 | 4.0 | | | | | 60 | 4.2 | 40 | 4.1 | 35 | 6.0 | 60 | 4.0 | | | 35 | 4.8 |
| | | | | | | 91 | 4.2 | 59 | 4.0 | 50 | 4.6 | 80 | 3.9 | | | 45 | 4.2 |
| | | | | | | | | | | 75 | 4.2 | 108 | 3.9 | | | 60 | 4.0 |
| | | | | | | | | | | 100 | 4.0 | | | | | 90 | 4.0 |
| | | | | | | | | | | 125 | 3.8 | | | | | 116 | 4.0 |
| | | | | | | | | | | 150 | 3.8 | | | | | | |
| | | | | | | | | | | 200 | 3.8 | | | | | | |
| | | | | | | | | | | 250 | 3.7 | | | | | | |

2/ Station at offshore end of gang of nets.
3/ Station at inshore end of gang of nets.

## STATIONS OFF LUDINGTON-FRANKFORT

Temperatures were obtained on 26 days off the Ludington-Frankfort shore during June 18-August 5, 1930, and May 15-September 18, 1931, at 6 shallow stations with depths 47 to 63 meters (154 to 207 ft.) averaging 56 meters (184 ft.) and at 11 deep stations with depths 89 to 250 meters (292 to 820 ft.) averaging 144 meters (472 ft.) (table 4).

The shallow-water surface temperature rose from 8.7° (47.7° F.) after June 18, 1930, to temperatures that fluctuated from 12.2° to 14.2° (54.0° to 57.6° F.) through July and reached a peak of 19.9° (67.8° F.) on August 5, the last date. In 1931 it progressed from 4.1° (39.4° F.) on May 15 to 21.6° (70.9° F.) on July 30 and then varied from 19.0° to 19.9° (66.2° to 67.8° F.) except on August 26 and 27 when the temperature dropped to 13° (55° F.).

At the deep stations the surface temperature increased consistently from 7.4° to 20.0° (45.3° to 68.0° F.) in 1930 and from 4.0° (39.2° F.) to a maximum of 21.5° (70.7° F.) on August 18 in 1931 and then fluctuated from 17.1° to 20.2° (62.8° to 68.4° F.) excluding the sudden decline to 14° (57° F.) on August 26. The surface warmed more slowly at the deep stations in both years but by late July and thereafter their temperatures generally exceeded those of the shallow stations.

The reduction in surface temperature of about 7° (13° F.) between August 18-19 and August 26-27, 1931, in both deep and shallow stations was an unusual summer incident, although an upwelling had also dropped the surface temperature to the same extent on August 17 at a station between Grand Haven and Muskegon. The decrease continued in the subsurface waters down to the 8-meter (26 ft.) level on August 26 at the shallow station and to the bottom on the next day and nearly to the bottom on the 26th at the deep station. The reduction of the upper-level temperatures resulted from the cold air, and the severe storm that started late on August 19 and continued to the early morning of the next day. This storm increased the swell and current. Adverse weather continued so that no hydrographic data could be collected during August 20-25. However, an upwelling of cold water may also have reduced the temperatures of the lower levels at the deep station.

The subsurface temperatures of both years followed, with exceptions on only three dates (July 8 and 23, 1930, and August 18, 1931), the direction of changes of the surface temperatures either to the bottom or down to depths that ranged from about 5 to 48 meters (16 to 158 ft.) in 1930 and 5 to 70 meters (16 to 230 ft.) in 1931. The temperatures below these upper layers, if not reversed to the bottom, were either changed again or fluctuated at the greater depths.

A late-winter temperature was still evident on May 15 and 19, 1931, when a degree of 3.8 (38.8° F.) was recorded at 20 meters (66 ft.) at a shallow station and at 10 meters (33 ft.) at a deep station. No temperatures below 4° (39.2° F.) were observed at any shallow station after mid-June, except on July 30, 1931, when a bottom temperature of 3.9° (39.0° F.) occurred at a depth of only 47 meters (154 ft.), the result of an upwelling revealed by the temperatures of July 22 and 30. The rising of cold water also took place on other dates. The temperature was decreased on July 8, 1930, up to at least the 5-meter (16 ft.) level at both stations and on August 18, 1931, at the shallow station.

A temperature of 3.9° (39.0° F.) was recorded up to July 10 in 1930 but only at the bottom of deep stations. In 1931 the deep-station temperatures below 4° (39.2° F.) gradually moved to greater depths with the advance of the season until in certain waters they had disappeared. The temperature of 3.9° (39.0° F.) had been lowered to depths of 60 to 65 meters (197 to 213 ft.) during May 29-June 23 and 85 to 95 meters (279 to 312 ft.) on June 24. The other records of 3.9° (39.0° F.) obtained on July 20, 22, and September 4 at depths of 75 to 100 meters (246 to 328 ft.) were no doubt the results of the upwelling of water from greater depths, as evidenced by the fact that temperatures of the same levels at other stations were higher during the same period. In the deepest basin of the lake with depths of 189 to 250 meters (620 to 820 ft.) the temperatures ranged from 3.8° to 4.0° (38.8° to 39.2° F.) at the level of 125 meters (410 ft.) and from 3.6° to 3.8° (38.5° to 38.8° F.)

in the greater depths during the period from June 24 to August 27, 1931. The low temperatures near and at the bottom of these deep stations were no doubt the result of increased pressure that decreased the temperatures of maximum density.

Not until July did the deep-water temperatures of 1930 approached and finally surpassed the shallow-water temperatures at various levels including all depths on the last two paired dates. In 1931 the temperatures were lower at the deep than at the shallow stations at all depths in mid-May but only down to depths of 8 to 25 meters (26 to 82 ft.) through August 18. On the last three paired dates the deep-station temperatures were higher down to levels of 12 to 15 meters (39 to 49 ft.) and to the bottom on August 27. The upper waters, including the surface, were warmer during the summer months of 1931 than of 1930.

Five-degree (41° F.) water was generally restricted during the summer of 1930 to depths of 30 to 37 meters (98 to 121 ft.) at the shallow stations and 35 to 49 meters (115 to 161 ft.) at the deep stations, except on June 18 and 27 when it was found at a level of about 15 meters (49 ft.) at a deep station. In 1931 this temperature, which did not appear until early June, was recorded at depths of 20 to 32 meters (66 to 105 ft.) in shallow water and 25 to 50 meters (82 to 164 ft.) in deep water.

The bottom temperature of the shallow stations reached a maximum of 4.6° on June 27, 1930, and 4.5° on August 26, 1931, (40.3° and 40.1° F.) but on other dates fluctuated from 4.0° to 4.3° (39.2° to 39.7° F.) and 3.8° to 4.2° (38.8° to 39.6° F.) in 1930 and 1931 respectively. At the deep stations it ranged from 3.9° to 4.0° (39.0° to 39.2° F.) in 1930 and from 3.8° to 4.0° (38.8° to 39.2° F.) in 1931, except the single maximum of 4.2° (39.6° F.) and the temperatures of 3.6° and 3.7° (38.5° and 38.7° F.) recorded at depths of 220 to 250 meters (722 to 820 ft.).

A thermocline had not been observed in 1930 until August 5 but only at the shallow station at depths of 17 to 20 meters (56 to 66 ft.). The first thermocline of 1931 was recorded on June 23 at depths of 10 to 12 meters (33 to 39 ft.) at a deep station. It probably was also present at the same level on June 24 at the 220-meter (722 ft.) station. Not until July 6 did a thermocline persist to the last date at all stations, in contrast to the situation in 1930. Except on August 27, the thermocline was always at a greater depth in the shallow than in the deep areas on the same dates. In both waters the thermocline fluctuated between depths of 5 and 28 meters (16 and 92 ft.). The ranges of the thermocline depth intervals and temperatures were very closely the same in both waters. They varied from 2 to 7 meters (7 to 23 ft.) and 2° to 13° (4° to 23° F.) with general averages of 4 meters (13 ft.) and 7° (13° F.). On September 4 two thermoclines had formed between depths of 15 and 23 meters (49 and 76 ft.).

## STATIONS OFF WAUKEGAN

Temperatures off the Waukegan shore were obtained only on November 11 in 1930 and on five dates in 1931 from May 11 to November 2 (table 5). The 1930 station was 34 meters deep (112 ft.). The depths of the three 1931 stations ranged from 50 to 88 meters (164 to 289 ft.) and averaged 70 meters (230 ft.).

The surface temperatures taken on the same day varied very little with the depths. They increased from 4.7° (40.5° F.) on May 11 to 20.9° (69.6° F.) on June 30 and decreased to 11.0° (51.8° F.) on November 2. On November 11, 1930, the temperature of 5.8° (42.4° F.) had extended from top to bottom. On May 26 and June 30, 1931, 5-degree (41° F.) water was confined to depths of 30 to 40 meters (89 to 131 ft.) but was lowered to 47 to 52 meters (154 to 171 ft.) in the fall. The 1931 bottom temperatures ranged from 4.0° in the spring to 4.8° in the fall (39.2° to 40.6° F.).

The subsurface temperatures increased at all depths on May 26 to nearly the same degrees at both stations but only down to 25 meters (82 ft.) in June when they were higher at the deeper station at a level of 10 meters (33 ft.) and beyond. In October and November 1931 the waters had cooled off down to about 10 meters (33 ft.) but were still warmer than those of June at the lower levels. The thermoclines were

Table 5.--Temperatures C° of Lake Michigan off Waukegan, Illinois, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C12 Sta. 23 Nov. 11 D 34 | | C2 Sta. 112 May 11 D 56 | | C2 Sta. 113 May 11 D 88 | | C3 Sta. 112 May 26 D 50 | | C3 Sta. 113 May 26 D 83 | |
|---|---|---|---|---|---|---|---|---|---|
| Air 13.8 | | Air 13.5 | | Air 13.6 | | Air 14.3 | | Air 14.3 | |
| S | 5.8 | S | 4.8 | S | 4.7 | S | 6.1 | S | 6.7 |
| 2 | 5.8 | 5 | 4.4 | 5 | 4.4 | 5 | 5.8 | 5 | 6.0 |
| 5 | 5.8 | 10 | 4.4 | 10 | 4.4 | 10 | 5.8 | 10 | 5.7 |
| 10 | 5.8 | 15 | 4.4 | 20 | 4.4 | 15 | 5.6 | 20 | 5.6 |
| 15 | 5.8 | 20 | 4.3 | 30 | 4.3 | 20 | 5.5 | 30 | 5.4 |
| 20 | 5.8 | 30 | 4.2 | 40 | 4.0 | 30 | 5.3 | 40 | 4.9 |
| 25 | 5.8 | 40 | 4.1 | 50 | 4.0 | 40 | 4.9 | 50 | 4.5 |
| 30 | 5.8 | 45 | 4.1 | 70 | 4.0 | 50 | 4.6 | 60 | 4.5 |
| 34 | 5.8 | 56 | 4.1 | 88 | 4.0 | | | 83 | 4.3 |

| C6 Sta. 112 June 30 D 55 | | C6 Sta. 113 June 30 D 86 | | C16 Sta. 149 Oct. 22 D 68 | | C17 Sta. 149 Nov. 2 D 75 | |
|---|---|---|---|---|---|---|---|
| Air 26.8 | | Air 28.7 | | Air 16.3 | | Air 10.3 | |
| S | 20.9 | S | 20.7 | S | 11.8 | S | 11.0 |
| 4 | 20.3 | 4 | 19.8 | 5 | 11.6 | 5 | 11.0 |
| 8 | 15.2 | 7 | 16.8 | 10 | 11.6 | 10 | 11.0 |
| 10 | 9.8 | 10 | 13.1 | 15 | 11.6 | 15 | 11.0 |
| 12 | 7.5 | 12 | 10.8 | 20 | 11.6 | 20 | 10.9 |
| 14 | 6.6 | 14 | 9.4 | 25 | 11.6 | 25 | 10.8 |
| 16 | 6.3 | 16 | 8.0 | 28 | 11.6 | 35 | 10.8 |
| 18 | 6.2 | 18 | 7.2 | 30 | 11.6 | 40 | 10.6 |
| 20 | 6.0 | 20 | 6.3 | 33 | 11.3 | 44 | 5.8 |
| 25 | 5.5 | 25 | 5.8 | 35 | 10.0 | 47 | 5.0 |
| 30 | 5.0 | 35 | 5.2 | 40 | 7.9 | 50 | 4.8 |
| 35 | 4.7 | 45 | 4.8 | 53 | 4.9 | 75 | 4.7 |
| 40 | 4.7 | 55 | 4.5 | 68 | 4.8 | | |
| 45 | 4.4 | 65 | 4.3 | | | | |
| 55 | 4.4 | 75 | 4.1 | | | | |
| | | 86 | 4.0 | | | | |

Table 6.--Temperatures C° of Lake Michigan off Kenosha and Racine, Wisconsin, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C3 | C4 | C5 | C5 | C12 | C13 | C13 | C2 |
|---|---|---|---|---|---|---|---|
| Sta. 27 | Sta. 28 | Sta. 27 | Sta. 28 | Sta. 25 | Sta. 29 | Sta. 25 | Sta. 103 |
| July 12 | July 28 | Aug. 8 | Aug. 8 | Nov. 10 | Nov. 13 | Nov. 14 | May 8 |
| D 62 | D 113 | D 57 | D 113 | D 65 | D 83 | D 70 | D 68 |
| Air 22.0 | Air 24.2 | Air 27.5 | Air 26.4 | Air 13.2 | Air 11.8 | Air 11.6 | Air 6.0 |
| S 18.5 | S 21.1 | S 23.4 | S 23.1 | S 7.8 | S 7.1 | S 7.3 | S 3.8 |
| 6 18.3 | 6 20.7 | 5 23.0 | 5 22.2 | 10 7.6 | 8 7.1 | 5 7.3 | 5 3.8 |
| 8 18.0 | 12 16.8 | 10 21.1 | 10 20.4 | 17 7.5 | 18 7.1 | 10 7.3 | 10 3.8 |
| 11 14.7 | 15 16.0 | 12 19.3 | 14 17.8 | 25 7.4 | 28 7.0 | 20 7.1 | 15 3.8 |
| 14 11.0 | 18 14.6 | 15 13.7 | 17 13.7 | 30 7.4 | 38 6.9 | 30 6.7 | 20 3.8 |
| 17 8.7 | 22 11.9 | 16 13.0 | 20 13.2 | 35 7.2 | 48 6.2 | 40 6.3 | 30 3.8 |
| 22 7.0 | 30 5.6 | 18 9.3 | 23 10.3 | 40 6.9 | 58 4.7 | 50 6.1 | 40 3.8 |
| 27 5.9 | 50 4.3 | 20 7.8 | 26 8.1 | 45 6.4 | 68 4.6 | 60 5.5 | 50 3.8 |
| 42 4.5 | 113 3.9 | 22 6.7 | 30 6.1 | 50 6.3 | 83 4.5 | 70 5.1 | 68 3.8 |
| 62 4.5 | | 25 6.0 | 50 4.2 | 55 6.0 | | | |
| | | 30 5.6 | 113 4.0 | 65 6.0 | | | |
| | | 40 4.8 | | | | | |
| | | 57 4.5 | | | | | |

| C3 | C3 | C5 | C5 | C6 | C6 | C7 | C7 |
|---|---|---|---|---|---|---|---|
| Sta. 116 | Sta. 104 | Sta. 116 | Sta. 121 | Sta. 116 | Sta. 121 | Sta. 121 | Sta. 131 |
| May 22 | May 23 | June 15 | June 15 | June 29 | June 29 | July 10 | July 17 |
| D 58 | D 97 | D 55 | D 96 | D 55 | D 97 | D 96 | D 109 |
| Air 13.6 | Air 9.8 | Air 19.2 | Air 15.6 | Air 25.8 | Air 25.4 | Air 19.5 | Air 28.8 |
| S 5.3 | S 5.0 | S 12.4 | S 10.6 | S 19.5 | S 19.1 | S 19.4 | S 24.2 |
| 5 4.9 | 5 4.8 | 5 12.4 | 5 10.2 | 4 17.0 | 4 16.0 | 4 19.0 | 4 21.8 |
| 10 4.9 | 10 4.6 | 10 10.4 | 10 9.1 | 7 16.1 | 7 15.4 | 7 18.9 | 7 19.9 |
| 20 4.9 | 20 4.6 | 15 8.4 | 15 8.3 | 10 13.0 | 10 14.2 | 10 17.4 | 10 19.1 |
| 30 4.7 | 30 4.5 | 20 5.9 | 22 8.1 | 12 9.3 | 12 13.4 | 12 15.4 | 12 18.0 |
| 40 4.7 | 40 4.4 | 25 5.6 | 30 7.2 | 14 8.3 | 14 11.9 | 14 11.5 | 14 16.6 |
| 50 4.5 | 50 4.3 | 30 5.3 | 40 5.4 | 16 7.6 | 16 10.3 | 16 9.3 | 16 13.3 |
| 58 4.5 | 70 4.1 | 35 5.0 | 50 4.5 | 18 7.0 | 18 8.4 | 18 8.6 | 18 11.1 |
| | 97 3.9 | 40 4.8 | 65 4.3 | 20 6.4 | 20 7.9 | 20 8.5 | 20 8.5 |
| | | 50 4.4 | 80 4.1 | 25 5.5 | 25 5.8 | 21 7.2 | 25 6.6 |
| | | 55 4.4 | 96 4.0 | 30 5.1 | 30 5.7 | 23 6.7 | 35 5.0 |
| | | | | 40 4.8 | 40 5.6 | 25 6.0 | 45 4.7 |
| | | | | 50 4.5 | 50 4.5 | 45 5.1 | 60 4.4 |
| | | | | 55 4.4 | 60 4.4 | 55 4.4 | 75 4.1 |
| | | | | | 70 4.4 | 65 4.4 | 90 4.0 |
| | | | | | 80 4.3 | 80 4.3 | 109 4.0 |
| | | | | | 97 4.1 | 96 4.2 | |

| C9 | C9 | C12 | C14 | C15 | C16 |
|---|---|---|---|---|---|
| Sta. 130 | Sta. 131 | Sta. 136 | Sta. 144 | Sta. 144 | Sta. 144 |
| Aug. 6 | Aug. 6 | Sept. 2 | Sept. 28 | Oct. 9 | Oct. 21 |
| D 70 | D 103 | D 60 | D 106 | D 107 | D 107 |
| Air 27.1 | Air 27.3 | Air 20.6 | Air 18.0 | Air 18.0 | Air 18.4 |
| S 21.8 | S 24.4 | S 19.8 | S 16.6 | S 16.8 | S 13.6 |
| 5 19.8 | 6 23.0 | 5 19.8 | 5 16.6 | 5 16.8 | 5 13.6 |
| 8 17.3 | 11 22.6 | 10 19.8 | 10 16.5 | 10 16.8 | 10 13.6 |
| 11 15.6 | 13 22.2 | 14 19.8 | 15 16.5 | 15 16.6 | 15 13.5 |
| 13 14.8 | 15 13.5 | 18 19.8 | 19 16.5 | 20 16.6 | 21 13.4 |
| 15 10.6 | 17 11.2 | 20 19.8 | 21 16.5 | 22 16.6 | 24 13.4 |
| 17 7.8 | 20 9.9 | 22 19.3 | 23 16.5 | 24 13.3[2] | 27 13.4 |
| 20 6.5 | 25 7.5 | 23 15.0 | 25 16.5 | 26 12.4 | 30 13.4 |
| 25 5.8 | 30 6.0 | 24 12.2[1] | 30 15.4 | 28 10.0 | 32 11.6 |
| 35 4.8 | 40 5.0 | 25 11.7 | 32 7.3 | 30 7.6 | 35 10.7 |
| 45 4.5 | 50 4.5 | 30 6.2 | 35 5.9 | 32 5.8 | 37 9.0 |
| 55 4.5 | 65 4.2 | 35 5.0 | 37 5.5 | 35 5.6 | 40 8.9 |
| 70 4.4 | 80 4.2 | 45 4.7 | 40 5.4 | 40 5.0 | 45 6.1 |
| | 103 4.2 | 60 4.6 | 50 4.3 | 50 4.5 | 50 4.9 |
| | | | 70 4.2 | 70 4.5 | 70 4.7 |
| | | | 106 4.2 | 107 4.5 | 107 4.6 |

1/ Only 0.5 degree change between 24 and 25.
2/ Only 0.9 degree change between 24 and 26.

recorded at depths of 4 to 12 meters (13 to 39 ft.) on June 30 and 40 to 44 meters (131 to 144 ft.) on November 2. None was observed in May or on October 22. The thermocline temperatures were reduced from 7.5° to 20.3° (45.5° to 68.5° F.) to 5.8° to 10.6° (42.4° to 51.1° F.). On the last two dates the temperature had approached uniformity between 10 and 12 degrees (50° and 54° F.) from the surface to at least 35 meters (115 ft.).

## STATIONS OFF KENOSHA-RACINE

Temperatures were obtained on 18 days off the Kenosha-Racine shore during July 12-November 14, 1930, and May 8-October 21, 1931, at 6 shallow stations with depths of 55 to 70 meters (180 to 230 ft.) that averaged 62 meters (203 ft.) and at 6 deep stations with depths of 83 to 113 meters (272 to 371 ft.) that averaged 102 meters (335 ft.) (table 6).

The surface temperatures of both years increased progressively in both waters during the early periods of records reaching on August 6 and 8 the maxima that ranged from 22° to 24° (72° to 75° F.). By mid-November in 1930 the temperature had been reduced to 7° (45° F.). The 1931 surface temperatures rose more slowly at the deep than at the shallow stations even though they had reached a higher climax at the deep station on August 6. The few comparable records suggest that the surface waters were warmer in 1931 than in 1930 during the summer months.

The temperatures of the upper subsurface waters followed the trends of the surface temperatures except on September 2, 1931, when a uniform temperature of 19.8° (67.6° F.) had extended from the surface to a depth of 20 meters (66 ft.). In 1930 the temperatures had risen in August above those of July down to depths of 20 and 14 meters (66 and 46 ft.) respectively in the shallow and deep waters. In November, the water had cooled in the upper 20 to 28 meters (66 to 92 ft.) to about 7° (45° F.) but the temperatures of the greater depths had actually increased. These changes reduced the differences between the surface and bottom temperatures to an average of only 2.2° (4.0° F.).

In 1931 the temperatures of both waters had increased progressively to June 15 at nearly all depths, and thereafter to August 6 the increases were restricted to the maximum depths that ranged from 12 to 25 meters (39 to 82 ft.). The temperatures had increased at the shallow station on September 2 at all depths but had decreased at the deep station down to the 13-meter (43 ft.) level on September 28, remained about the same to a depth of 22 meters (72 ft.) on October 9, and declined on October 21 to a depth of 22 meters (72 ft.). On these last two dates the temperatures had risen respectively at depths below 40 and 23 meters (131 and 75 ft.). Temperatures below the shifted temperatures of the upper waters remained constant, reversed to the bottom, or fluctuated at different depths. Uniform temperatures had developed during both autumns at levels above depths that ranged from 20 to 35 meters (66 to 115 ft.).

Five-degree (41° F.) water appeared late May 1931 near the surface. In both years this temperature was restricted during June-September to depths of 32 to 37 meters (105 to 121 ft.) at the shallow stations and 35 to 46 meters (115 to 151 ft.) at the deep stations. In late October and early November it had descended to 50 to 56 meters (164 to 184 ft.) in deep water but disappeared early November in shallow water.

The bottom temperatures, although always higher in the shallow than in the deep water at the same time of year, increased very slowly during the summer months and reached their maxima in the fall. On May 8, 1931, the shallow-water temperature was 3.8° (38.8° F.) at all depths. On later dates in both years the bottom temperatures of the shallow stations varied from 4.4° to 4.6° (39.9° to 40.3° F.) but rose to 5.1° to 6.0° (41.2° to 42.8° F.) in November 1930. At the deep stations they ranged from 3.9° to 4.2° (39.0° to 39.6° F.) but increased in October and November to 4.5° to 4.6° (40.1° to 40.3° F.). The bottom waters of the deep stations warmed more slowly than and apparently rose not as high as those of the shallow stations.

In 1930 a thermocline was recorded on July 12 in shallow water at depths of 8 to 14 meters (26 to 46 ft.) but none on July 28 in deep water. On August 8, how-

ever, one occurred at both stations at depths somewhere between 12 and 18 meters (39 and 59 ft.). No thermocline was observed in November. The earliest thermocline recordin in 1931 was reported on June 29 at both stations. It persisted on the subsequent dates to October 9 but disappeared on October 21. It had gradually descended in both waters with the advance of the season from levels of about 10 to 20 meters (33 to 66 ft.) to 22 to 32 meters (72 to 105 ft.). A double thermocline was recorded on July 10, 1931. The thermal gradients ranged from 2° to 13° (4° to 23° F.) with an average of 7.7° (13.9° F.) and covered depth intervals of 2 to 8 meters (7 to 26 ft.) with an average of 4.8 meters (15.8 ft.).

## STATIONS OFF MILWAUKEE-PORT WASHINGTON-SHEBOYGAN

Temperatures off the Milwaukee-Sheboygan shore were obtained on 17 days during June 23-August 9, 1930, and June 1-September 23, 1931, at 7 shallow stations with depths of 60 to 84 meters (197 to 276 ft.) and at 6 deep stations with depths of 102 to 146 meters (335 to 479 ft.) that averaged 73 and 126 meters (240 and 413 ft.) (table 7).

The 1930 surface temperature reached a maximum of 19.6° (67.3° F.) on July 29 in the shallow water and 19.9° (67.8° F.) on August 9 in the deep water, the last dates of observation. Except for the shallow-water records of July 1 and 2, the temperatures tended to increase during the period of observation. The waters warmed at about the same rate at both groups of stations, in contrast to other areas except off Waukegan. In 1931 the surface temperature of both waters rose from about 8° (46° F.) on June 1 and 2 to a maximum of 21.7° (71.1° F.) on July 24 at a deep station and 19.4° (66.9° F.) on August 31 in shallow water. The surface waters appeared to have been warmer at the deep than at the shallow stations in the fall and also in 1931 than in 1930 during the summer.

Temperatures of the subsurface shallow and deep waters followed the seasonal trend of the 1930 and 1931 surface temperatures down to depths that either extended to the bottom or ranged from about 5 to 40 meters (16 to 131 ft.). The temperatures below these upper layers did or did not shift again at different depths. Seldom did the upper-level temperatures of any region decline during midsummer as much as they did (2.4° and 33.3° C.; 4.3° and 5.9° F.) in the shallow water on July 1 and 2, 1930. On the first the water had cooled near the surface but on the next day down to a depth of at least 18 meters (59 ft.). This reduction may have been caused by the unusual cold air, its temperature having been lowered from about 22° to 13° (72° and 43° F.).

Five-degree (41° F.) water descended gradually at the shallow stations from about 25 (82 ft.) to 44 meters (144 ft.) with the advance of the season during June-September. At the deep stations, however, this degree water fluctuated between 25 and 36 meters (82 and 118 ft.) during June and July and then descended in August and September to a maximum of 43 meters (141 ft.).

The recorded bottom temperatures fluctuated from 4.0° to 4.5° (39.2° to 40.1° F.) in the shallow waters and from 3.8° to 4.0° (38.8° to 39.2° F.) in the deep waters. On July 9, 1931, the bottom temperature of 3.9° (39.0° F.) had risen to as high as 65 meters (213 ft.) at a deep station and was still recorded at 80 meters (262 ft.) on July 25 and August 13. An upwelling must have taken place.

A thermocline was recorded earlier in 1930 than in 1931. In 1930 it was present at all stations from June 23 to August 9 except on July 1 when it had been obliterated at the shallow station by warm water. In 1931 no thermocline was reported in June. The first one was recorded on July 9 and others were observed on all subsequent dates except in the shallow water on September 23. The thermoclines had fluctuated between depths of 10 and 25 meters (33 and 82 ft.) during the summer months except on June 23, 1930, when a deep-station thermocline had formed at depths of 4 to 7 meters (13 to 23 ft.). In the fall the existing thermoclines had been lowered to depths of 19 to 30 meters (62 to 98 ft.). A double thermocline was recorded on August 13, 1931, between 14 and 25 meters (46 and 82 ft.) at a deep station. The thermal gradients varied from 4° to 13° (7° to 23° F.) with an average of 7.3° (13.1° F.) and covered depth intervals of 2 to 9 meters (7 to 30 ft.) with an average of 4.6 meters (15.1 ft.).

Table 7.--Temperatures C° of Lake Michigan off Milwaukee, Port Washington, and Sheboygan, Wisconsin, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[ C = cruise; D = maximum depths; S = surface ]

| C1 Sta. 31 June 23 D 73 Air 22.0 | C1 Sta. 32 June 23 D 111 Air 21.2 | C2 Sta. 31 July 1 D 71 Air 13.4 | C2 Sta. K July 2 D 77 Air -- | C3 Sta. 31 July 15 D 74 Air 21.6 | C3 Sta. 32 July 15 D 109 Air 20.0 | C3 Sta. 33 July 18 D 125 Air 20.1 | C3 Sta. 34 July 18 D 60 Air 22.4 |
|---|---|---|---|---|---|---|---|
| S 14.5 | S 15.9 | S 12.1 | S 11.2 | S 16.7 | S 16.8 | S 16.8 | S 17.5 |
| 3 14.1 | 4 14.9 | 5 12.0 | 5 10.4 | 5 15.9 | 7 15.7 | 6 16.6 | 5 16.8 |
| 8 11.8 | 7 11.4 | 9 11.9 | 10 9.7 | 10 15.8 | 14 15.3 | 11 15.7 | 9 16.6 |
| 10 11.6 | 10 10.5 | 13 9.4 | 14 5.6 | 14 15.8 | 17 15.2 | 13 15.5 | 12 15.3 |
| 13 7.1 | 13 9.8 | 16 7.4 | 17 5.2 | 17 15.6 | 20 12.4 | 15 12.5 | 15 11.1 |
| 18 5.8 | 16 8.9 | 21 6.0 | 22 5.1 | 20 8.5 | 23 8.5 | 16 10.0 | 18 8.9 |
| 23 5.0 | 21 7.0 | 26 5.0 | 27 5.0 | 25 6.0 | 26 6.2 | 18 8.0 | 22 6.8 |
| 28 4.8 | 31 5.1 | 31 4.7 | 37 4.7 | 33 4.8 | 36 4.9 | 20 6.6 | 32 4.5 |
| 33 4.5 | 71 4.2 | 71 4.0 | 77 4.0 | 74 4.1 | 71 4.2 | 27 4.9 | 60 4.1 |
| 41 4.5 | 111 4.0 | | | | 109 4.0 | 35 4.6 | |
| 71 4.5 | | | | | | 75 4.0 | |
| 73 ? | | | | | | 125 4.0 | |

| C4 Sta. 33 July 29 D 125 Air 22.7 | C4 Sta. 35 July 29 D 69 Air 20.4 | C5 Sta. 33 Aug. 9 D 125 Air 22.6 | C4 Sta. 115 June 1 D 76 Air 17.4 | C4 Sta. 101 June 2 D 102 Air 13.6 | C5 Sta. 120 June 13 D 137 Air 18.9 | C6 Sta. 115 June 27 D 76 Air 20.1 | C7 Sta. 120 July 9 D 115 Air 22.3 |
|---|---|---|---|---|---|---|---|
| S 19.5 | S 19.6 | S 19.9 | S 8.1 | S 8.4 | S 11.3 | S 15.5 | S 17.2 |
| 5 18.8 | 6 19.5 | 5 19.9 | 5 7.0 | 5 7.4 | 5 10.5 | 5 14.2 | 4 17.2 |
| 11 18.5 | 11 18.5 | 10 17.6 | 10 6.1 | 10 6.6 | 10 8.1 | 9 13.4 | 7 17.1 |
| 14 17.8 | 14 14.3 1/ | 14 12.4 | 20 5.8 | 20 5.6 | 15 7.3 | 11 12.9 | 10 14.5 |
| 15 16.7 | 17 12.0 | 17 9.9 | 30 4.8 | 30 4.9 | 25 5.8 | 13 11.2 | 12 11.3 |
| 17 11.6 | 20 8.7 | 20 7.5 | 45 4.6 | 40 4.5 | 35 4.5 | 15 9.4 | 14 9.2 |
| 18 9.0 | 25 6.4 | 23 6.4 | 60 4.5 | 55 4.3 | 45 4.3 | 17 8.2 | 16 7.6 |
| 20 7.0 | 35 4.7 | 26 6.1 | 76 4.4 | 75 4.3 | 60 4.0 | 20 7.2 | 18 6.8 |
| 25 5.5 | 69 4.3 | 30 5.6 | | 102 4.0 | 75 4.0 | 25 6.4 | 20 6.2 |
| 35 4.8 | | 60 4.0 | | | 100 4.0 | 30 5.2 | 25 5.2 |
| 75 4.0 | | 125 3.9 | | | 137 3.9 | 35 5.0 | 30 4.8 |
| 125 4.0 | | | | | | 40 4.8 | 40 4.3 |
| | | | | | | 50 4.6 | 50 4.2 |
| | | | | | | 60 4.5 | 65 3.9 |
| | | | | | | 76 4.4 | 80 3.9 |
| | | | | | | | 100 3.9 |
| | | | | | | | 115 3.9 |

| C8 Sta. 133 July 24 D 139 Air 21.6 | C10 Sta. 133 Aug. 13 D 146 Air 20.0 | C12 Sta. 138 Aug. 31 D 68 Air 16.0 | C13 Sta. 133 Sept. 11 D 146 Air 25.5 | C14 Sta. 145 Sept. 23 D 84 Air 17.3 | C14 Sta. 146 Sept. 23 D 133 Air 18.1 |
|---|---|---|---|---|---|
| S 21.7 | S 20.0 | S 19.4 | S 21.1 | S 17.4 | S 18.6 |
| 4 21.5 | 5 20.0 | 5 19.4 | 5 21.1 | 5 15.9 | 5 18.6 |
| 7 21.3 | 10 19.9 | 10 19.3 | 9 20.8 | 9 14.4 | 10 18.5 |
| 10 20.3 | 14 19.7 | 13 19.3 | 12 20.2 | 11 13.8 | 13 18.5 |
| 12 16.8 | 17 16.5 | 15 19.3 | 15 19.8 | 13 13.2 | 16 17.8 |
| 14 12.4 | 20 10.5 | 17 19.3 | 20 19.4 | 15 12.9 | 19 15.3 |
| 16 9.5 | 23 9.3 | 19 19.2 | 22 19.2 | 17 12.8 | 22 9.6 |
| 18 7.2 | 25 6.4 | 21 13.9 | 24 18.4 | 19 12.4 | 25 7.0 |
| 20 6.6 | 35 4.6 | 23 10.0 | 26 18.0 | 21 12.2 | 30 5.4 |
| 25 5.0 | 45 4.2 | 25 8.5 | 28 16.5 | 23 12.1 | 35 5.1 |
| 30 4.8 | 60 4.2 | 30 6.0 | 30 6.2 | 25 11.7 | 45 4.8 |
| 40 4.4 | 80 3.9 | 40 4.4 | 55 4.0 | 30 10.5 | 60 4.2 |
| 60 4.2 | 100 3.9 | 50 4.4 | 80 4.0 | 35 9.0 | 75 4.2 |
| 80 3.9 | 120 3.9 | 68 4.3 | 110 4.0 | 45 4.6 | 100 4.0 |
| 100 3.9 | 146 3.9 | | 146 3.9 | 60 4.6 | 133 4.0 |
| 120 3.9 | | | | 84 4.5 | |
| 139 3.8 | | | | | |

1/ Only 2.3 degrees change between 14 and 17.

Table 8.--Temperatures C° of Lake Michigan off Manitowoc, Two Rivers, and Kewaunee, Wisconsin, 1930 and 1931. Station (Sta.) numbers under 100 were occupied in 1930; those between 100 and 200 were occupied in 1931. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C1 | C1 | C3 | C3 | C4 | C4 | C5 |
|---|---|---|---|---|---|---|
| Sta. 36 | Sta. 37 | Sta. 36 | Sta. 37 | Sta. 36 | Sta. 37 | Sta. 36 |
| June 24 | June 24 | July 21 | July 21 | July 30 | July 30 | Aug. 12 |
| D 54 | D 145 | D 43 | D 145 | D 43 | D 140 | D 45 |
| Air 17.4 | Air 15.9 | Air 19.0 | Air 20.2 | Air 17.0 | Air 18.8 | Air 15.0 |
| S 10.6 | S 9.9 | S 16.7 | S 14.7 | S 16.5 | S 18.2 | S 16.5 |
| 4 10.1 | 5 9.3 | 5 15.6 | 10 14.2 | 6 16.4 | 9 18.1 | 5 16.7 |
| 9 9.8 | 10 8.7 | 10 13.5 | 14 12.6 | 11 9.4 | 14 14.0 | 9 16.6 |
| 14 8.8 | 15 7.5 | 14 11.2 | 17 10.3 | 14 6.5 | 17 10.7 | 11 16.5 |
| 19 6.2 | 20 6.4 | 17 9.2 | 20 7.8 | 17 5.3 | 20 8.5 | 13 16.5 |
| 24 5.1 | 25 5.6 | 20 7.1 | 23 7.1 | 20 4.7 | 24 7.0 | 15 16.2 |
| 29 5.0 | 35 4.9 | 24 5.2 | 30 5.9 | 24 4.7 | 30 6.2 | 18 14.8 |
| 39 4.2 | 75 3.9 | 28 4.9 | 70 4.0 | 43 4.5 | 70 4.0 | 21 12.3 |
| 54 4.2 | 145 3.9 | 43 4.6 | 145 3.9 | | 140 3.9 | 25 8.3 |
| | | | | | | 30 6.3 |
| | | | | | | 45 6.1 |

| C5 | C5 | C5 | C6 | C6 | C8 | C8 |
|---|---|---|---|---|---|---|
| Sta. 37 | Sta. 124 | Sta. 125 | Sta. 129 | Sta. 125 | Sta. 129 | Sta. 125 |
| Aug. 12 | June 25 | June 25 | July 8 | July 8 | Aug. 3 | Aug. 3 |
| D 143 | D 64 | D 82 | D 83 | D 87 | D 85 | D 87 |
| Air 18.7 | Air 17.5 | Air 20.0 | Air 17.8 | Air 24.2 | Air 17.8 | Air 19.8 |
| S 18.6 | S 13.5 | S 14.1 | S 16.7 | S 15.7 | S 17.4 | S 19.6 |
| 6 18.6 | 5 13.1 | 5 13.3 | 4 16.6 | 5 15.6 | 11 16.3 | 10 18.3 |
| 11 18.0 | 10 12.9 | 10 13.2 | 7 16.3 | 9 13.2 | 14 9.3 | 13 16.0 |
| 14 14.4 | 15 9.8 | 11 13.0 | 10 16.0 | 11 12.1 | 17 7.2 | 16 9.5 |
| 17 11.9 | 20 6.1 | 12 12.2 | 12 14.7 | 13 11.6 | 20 6.2 | 19 7.9 |
| 20 9.3 | 25 5.1 | 13 10.3 | 14 13.3 | 15 11.3 | 25 5.4 | 22 6.0 |
| 23 8.6 | 35 4.4 | 14 8.8 | 16 12.1 | 17 10.8 | 30 4.8 | 25 5.4 |
| 26 8.0 | 45 4.4 | 15 8.0 | 18 9.0 | 20 9.4 | 40 4.5 | 30 4.9 |
| 30 6.7 | 55 4.5 | 20 6.0 | 23 6.2 | 25 6.6 | 60 4.2 | 40 4.6 |
| 70 4.1 | 64 4.5 | 25 5.3 | 33 4.8 | 35 5.1 | 85 4.2 | 60 4.2 |
| 143 3.8 | | 35 4.6 | 43 4.6 | 45 4.6 | | 87 4.2 |
| | | 45 4.5 | 53 4.2 | 55 4.5 | | |
| | | 55 4.4 | 63 4.2 | 70 4.4 | | |
| | | 70 4.3 | 73 4.2 | 87 4.4 | | |
| | | 82 4.1 | 83 4.2 | | | |

| C9 | C9 | C12 | C12 | C14 | C15 |
|---|---|---|---|---|---|
| Sta. 134 | Sta. 135 | Sta. 134 | Sta. 143 | Sta. 147 | Sta. 147 |
| Aug. 12 | Aug. 12 | Sept. 10 | Sept. 10 | Oct. 5 | Oct. 15 |
| D 83 | D 163 | D 60 | D 148 | D 145 | D 172 |
| Air 20.2 | Air 19.0 | Air 19.3 | Air 22.6 | Air 16.3 | Air 14.3 |
| S 19.1 | S 19.4 | S 14.5 | S 17.3 | S 15.5 | S 12.1 |
| 5 19.1 | 8 19.0 | 5 14.5 | 5 17.3 | 5 15.5 | 5 11.9 |
| 8 19.1 | 11 19.0 | 9 12.4 | 8 17.2 | 10 15.4 | 10 11.9 |
| 11 19.1 | 14 19.0 | 11 10.5 | 11 16.3 | 15 15.3 | 15 11.8 |
| 13 19.0 | 17 18.9 | 13 8.8 | 14 12.8 | 17 15.3 | 18 11.7 |
| 15 18.8 | 20 18.2 | 15 6.5 | 17 10.5 | 19 15.3 | 20 11.4 |
| 17 18.8 | 22 15.9 | 17 5.7 | 20 9.0 | 21 15.2 | 22 11.0 |
| 20 18.8 | 24 11.8 | 19 5.5 | 23 8.0 | 24 12.2 | 24 10.5 |
| 25 18.2 | 25 9.1 | 21 4.8 | 25 6.4 | 27 9.2 | 26 10.3 |
| 30 15.8 | 30 5.5 | 23 4.6 | 30 4.8 | 30 7.8 | 28 10.1 |
| 34 14.8 | 35 5.0 | 25 4.5 | 35 4.6 | 35 6.4 | 30 10.0 |
| 37 12.2 | 45 4.6 | 27 4.5 | 40 4.4 | 45 4.8 | 35 9.2 |
| 40 8.2 | 60 4.2 | 30 4.4 | 70 3.9 | 65 4.1 | 40 7.8 |
| 50 5.6 | 80 4.0 | 35 4.4 | 95 3.8 | 90 4.0 | 60 4.8 |
| 60 4.5 | 100 3.8 | 45 4.4 | 120 3.8 | 120 4.0 | 90 4.0 |
| 70 4.5 | 120 3.8 | 60 4.4 | 148 3.8 | 145 4.0 | 120 3.9 |
| 83 4.4 | 140 3.8 | | | | 172 3.9 |
| | 163 3.8 | | | | |

## STATIONS OFF MANITOWOC-TWO RIVERS-KEWAUNEE

Temperatures off the Manitowoc-Kewaunee shore were obtained in 1930 on four dates from June 25 to August 12 and in 1931 on seven dates during June 25-October 15 (table 8). Depths of the 5 designated shallow stations varied from 43 to 54 meters (141 to 177 ft.) in 1930 and from 60 to 87 meters (197 to 285 ft.) in 1931 and of the 4 deep stations ranged from 140 to 145 meters (459 to 476 ft.) in 1930 and from 145 to 172 (476 to 564 ft.) in 1931. The averages of these four series were 46, 79, 143, and 157 meters (151, 259, 469, and 515 ft.).

The 1930 surface temperatures of the shallow stations rose from 10.6° (51.1° F.) on June 24 to 16.7° (62.1° F.) on July 21 and then remained virtually constant on the two dates thereafter. At the deep stations they rose at first more slowly than at the shallow stations but increased progressively from 9.9° (49.8° F.) to 18.6° (65.5° F.), surpassing the shallow-water temperatures about two degrees on the last two dates.

In 1931 the surface temperatures of the shallow stations increased progressively from 13.5° (56.3° F.) on June 25 to a maximum of 19.6° (67.3° F.) on August 3 and decreased to 14.5° (58.1° F.) on September 10, the last date. The depths of these stations were almost all about 1 3/4 greater than those of the designated shallow stations of 1930. Only on four dates from August 12 to October 15 were temperatures obtained at deep-water stations in 1931. Their surface temperatures declined progressively from 19.4° to 12.1° (66.9° to 53.8° F.). On corresponding dates the surface temperatures of the deep water exceeded those of the shallow water. These temperatures were higher in 1931 than in 1930 on the proximate dates.

The 1930 subsurface temperatures did not always follow the trend of the surface temperatures at the shallow stations, but those of the deep water did, having increased on each succeeding date down to at least 30 meters (98 ft.). The shallow-water temperatures of the upper 20 meters (66 ft.) did increase by July 21, but on July 30 upwelled water had reduced the temperatures up to at least the 11-meter (36 ft.) level (this had not occurred at the deep station). On August 12 they had increased considerably at all depths rising to around 16.5° (61.7° F.) throughout the upper 15 meters (49 ft.) and to an unusually high degree of 6.1° (43.0° F.) at the bottom. At the deep stations the subsurface temperatures gradually rose above those of the shallow stations at corresponding depths except at certain levels below 11 meters (36 ft.) on August 12 when warm water had reached a depth of at least 12 meters (69 ft.) at the shallow station.

In 1931 the subsurface temperatures of various upper levels tended to follow to a certain extent the seasonal trend of the surface temperatures of both shallow and deep water. Those of the shallow stations had increased by July 8 down to a level of 35 meters (115 ft.) but only to about 11 to 13 meters (36 to 43 ft.) on August 3 when apparently upwelled water had lowered the temperatures at different levels between 11 and 30 meters (36 and 98 ft.). By August 12 the temperatures had risen at all depths but noticeably down to a depth of 50 meters (164 ft.); those of the upper 25 meters (82 ft.) maintained a uniformity close to 19° (66° F.). On September 10 the temperatures had declined at all depths, perhaps the result of upwelling.

In the deep water the subsurface temperatures of the upper levels decreased progressively late in the year down to depths that ranged from 11 to about 45 meters (36 to 148 ft.) but those of the lower levels increased in October either to the bottom or to some depth between 60 and 90 meters (197 and 295 ft.). A nearly uniform temperature extended down to 20 to 22 meters (66 to 72 ft.) on all dates except September 10. Even though the two stations occupied on August 12 and September 10 were only about 7 miles apart, their temperatures differed markedly. In August they were the same down to the 17 meter (56 ft.) level; then the deep-water temperatures declined much more rapidly. In September the temperatures were considerably higher in the deep than in the shallow water at corresponding depths, especially in the upper 25 meters (82 ft.).

During the period from late June to early fall a temperature of 5° (41° F.) was usually confined to depths of 27 to 37 meters (89 to 121 ft.) at the shallow stations, except when cold water had welled

up (July 30, September 10) and usually warm water had descended (August 12, 1930 and 1931). This temperature was restricted to depths of 29 to 59 meters (95 to 194 ft.) at the deep stations where it had descended almost always with the advance of the season and exceeded the depths at the shallow stations on corresponding dates except on August 12, 1931.

Thermoclines had not formed on June 24 and July 21, 1930, in either shallow or deep water but did develop in both areas on July 30 and August 12. A thermocline appeared earlier in 1931 than in 1930 but not at both stations on June 25 and July 8. Most of the thermoclines occurred at levels between 11 and 18 meters (36 and 59 ft.). An upwelling raised the thermocline to 6 meters (20 ft.) on July 30, 1930, only at the shallow station, and on August 12 of both years and October 5, 1931, the descending of a uniform temperature developed a thermocline at depths between 20 and 27 meters (66 and 89 ft.) at three stations and between 37 and 40 meters (121 and 131 ft.) at station 134. The deep- and shallow-water thermoclines varied on the same dates with respect to depths and/or temperatures, the former usually shallower and their temperatures higher. No thermocline had developed on October 15, 1931. The thermal gradients ranged from 2° to 10° (4° to 18° F.) with an average of 5° (9° F.) and covered depth intervals of 2 to 8 meters (7 to 26 ft.) with an average of 3.6 meters (11.8 ft.).

## GENERALIZATIONS CONCERNING THE AREAS BELOW THE FRANKFORT-ALGOMA LINE

Surface temperatures were usually higher in shallow than in deep water on the same dates early in the summer. This situation was generally reversed during late July and early August until at least late fall in those regions where comparable data were available. Subsurface temperatures, either of the upper layers or at all depths, followed with few exceptions the trend of surface temperatures and were, therefore, also higher at the shallow than at the deep stations early in the summer but usually lower after late July or early August.

When the changes of the subsurface temperatures did not extend to the bottom those of the depths below the shifted upper level temperatures increased or decreased to the bottom or fluctuated at different depths or remained constant. The maximum depths of these upper temperatures ranged from 3 to 70 meters (10 to 230 ft.) although seldom beyond 50 meters (164 ft.). Occasionally upwellings decreased the temperatures of the upper strata somewhere between the surface and the 50-meter (164 ft.) level during the summer months. On two occasions cold air had also reduced the summer temperatures down to at least 18 meters (59 ft.) and perhaps deeper. Subsurface temperatures usually warmed most rapidly at the shallow than at the deep stations although the temperatures of the latter stations had gradually approached and often exceeded those of the former as the season advanced.

Surface temperatures of the deep-water stations off both shores averaged higher during the summer months (June-August) in 1931 than in 1930. The greatest discrepencies occurred in July. Differences between the two years were not consistent in the shallow waters.

Surface temperatures of the different regions increased with the advance of the season usually reaching the climax late July or early August. Since the monthly trends were similar in 1930 and 1931 and in shallow and deep waters off both shores, all of the data were combined and the averages recorded below. In general the temperature reached its peak in August and thereafter declined gradually but did not yet reach the May average in November.

| Month | Number of records | Surface temperatures C° | F° |
|---|---|---|---|
| May | 16 | 5.7 | 42.3 |
| June | 36 | 12.6 | 54.7 |
| July | 43 | 17.7 | 63.9 |
| August | 31 | 19.4 | 66.9 |
| September | 13 | 18.0 | 64.4 |
| October | 6 | 13.8 | 56.8 |
| November | 5 | 7.8 | 46.0 |

Differences between the temperatures of the several regions can be ascertained by comparing records obtained on the two nearest days within a period of four days. Forty-six percent of the records were obtained on successive days.

Surface temperatures of both shallow and deep water decreased almost consistently

(40 of 45 comparisons) from south to north along both shores during periods that ranged variously from May to November in 1930 and 1931. Reductions between the extreme regions along the east shore averaged 2.0° (3.6° F.) in shallow waters and 3.1° (5.6° F.) in deep waters. Along the west coast corresponding differences averaged 4.9° (8.8° F.) and 5.7° (10.3° F.). The regional surface temperatures had decreased to a greater degree along the west than along the east shore.

Waters of the southernmost areas were first to reach a temperature of 20° C. (68° F.). It was recorded on June 30 and July 1, 1931, but not until the latter half of July in the other regions. This temperature had not been recorded at all in the Manitowoc-Two Rivers region. As a matter of fact the 1930 and 1931 peak temperatures decreased from south to north along both shores and ranged from 24.4° (75.9° F.) to 18.6° (65.5° F.).

Comparisons of surface temperatures of opposite regions indicated that all waters off the east coast were generally colder to about the same degree (average 1.4° C.; 2.5° F.) than those off the west coast during the summer months, except the waters off St. Joseph-South Haven where the temperatures were higher (average 2.2° C.; 4.0° F.) than those off Waukegan and also off Kenosha-Racine (average 3.7° C.; 6.7° F.) except early in August. In August and September the general situation was also reversed in the other regions. The temperatures were then usually about 1° (1.8° F.) higher off the east shore.

The differences between the surface temperatures of the regions along the same shore or opposite each other were not the results of the variations of the depths of the water. The other probable causal factors were not investigated.

Thermoclines did not develop below the Frankfort-Algoma line until the latter half of June in any waters except the St. Joseph-South Haven area where one was recorded on June 9, 1931, but only in shallow water. The June records were actually isolated incidents. It was not until July, usually the latter half in 1930 and early July in 1931, that the thermoclines persisted throughout the season until fall. The available data indicated that they began to disappear gradually in October and completely in November. An unusual condition existed in the Ludington-Frankfort region in 1930 when a thermocline was formed on August 5 in shallow water but on none of the other dates of June, July, and August.

When comparing the deep- and shallow-water thermoclines of the same dates it was discovered that 67 percent had developed in overlapping depths and 33 percent in different strata. Nor did the depths of the thermoclines vary consistently with any of the different regions. The thermoclines did, however, on the average shift to greater depths with the advance of the season. Excluding the four extreme figures shown in parentheses, the combined ranges and averages of the depths of both years are listed below.

| Month | Number of records | Ranges | | Averages | |
|---|---|---|---|---|---|
| | | Meter | Feet | Meter | Feet |
| June | 8 | 4-18(33) | 13-59(108) | 8.8-12.5 | 29-41 |
| July | 28 | 6-25 | 20-82 | 11.9-17.0 | 39-56 |
| August | 28 | 5-28(40) | 16-92(131) | 13.2-17.3 | 43-57 |
| September | 12 | 11-32 | 36-105 | 19.9-23.5 | 65-77 |
| October | 2 | 21-30 | 69-98 | 21.5-28.5 | 70-94 |
| November | 1 | 40-44 | 131-144 | 40.0-44.0 | 131-144 |

Because the ranges of the thermocline depth intervals of a region did not vary consistently with the deep and shallow stations or with the two years, they have been combined. It was then found that the averages of these intervals as well as their thermal gradients were very closely the same in the different regions and exactly the same off both shores--4 meters (13 ft.) and 6° (10.8° F.).

The 1930 and 1931 thermocline temperatures did not appear to differ significantly on the proximate dates in either the shallow or deep waters of the same region. Only the temperatures of the upper layers were about twice as often somewhat higher in 1931 than in 1930. The data of both years may be combined whenever necessary.

As expected, the temperatures of nearly all (83 percent) of the deep- and shallow-water thermoclines, observed on the same dates, had overlapped. However, they were three times as often higher in general at the deep than at the shallow stations. In 71 percent of the comparisons the bottom temperatures of the thermoclines were higher in the deep than in the shallow water

and in 8 percent they were about equal in both waters. However, the upper temperatures were as often higher at the shallow as at the deep stations and were about equal in 8 percent of the comparisons.

Along both shores the thermocline temperatures generally decreased progressively from the southern to the northern areas. Comparisons were made on dates that were no more than three days apart--72 percent on successive days. The records also indicate that these temperatures were nearly always higher along the west opposite the east shore in the Grand Haven and the Kenosha and Milwaukee regions. In order to obtain sufficient data the comparable records involved a maximum of four days apart. Not enough information was available to compare the thermocline temperatures of the other opposite areas. The data of the various regions must not be considered as a unit.

In all regions the thermocline temperatures of both the shallow and deep stations generally increased progressively from June to August and then declined thereafter. Since the trend was the same in all areas and depths the combined data can be employed to indicate the general nature of the seasonal shift in the entire area below the Frankfort-Algoma line. The combined temperatures are shown below.

| Month | Number of records | Average range in temperatures in the thermocline | |
|---|---|---|---|
| | | C° | F° |
| June | 10 | 8.5-13.5 | 47.3-56.3 |
| July | 29 | 8.9-16.4 | 48.0-61.5 |
| August | 29 | 9.6-16.8 | 49.3-62.2 |
| September | 12 | 7.6-15.6 | 45.7-60.1 |
| October | 3* | 7.4-14.5 | 45.3-58.1 |
| November | 1* | 5.8-10.6 | 42.4-51.1 |

* Only of deep waters.

General conclusions can also involve the actual and interpolated calculated depths of the post-spring cold waters, especially those of 5° (41° F.) and less. It was first determined that the 1930 and 1931 depth records of the 5-degree water could be combined. Comparisons had been made between the individual records of shallow and deep stations, of the months, and of all regions. The general depth at all stations averaged 34 meters (112 ft.) in 1930 and 33 (108 ft.) in 1931.

Depths of the 5-degree (41° F.) water also fluctuated irregularly from month to month in all waters off both shores, so that the records of a single month may be combined for all regions. The average depths were practically the same during the months of May-September varying at random from 33 to 37 meters (108 to 121 ft.). In October and November, however, the depths averaged 51 meters (167 ft.).

The estimated depths of the 5-degree water did not vary consistently between the shallow and deep stations on the same dates. Only about half (55 percent) of the records indicated that this water had descended lower at the deep stations, down to an average of 35 meters (115 ft.) in comparison with 32 meters (105 ft.) in shallow waters.

In both the shallow and deep waters off both shores the depth of the 5-degree water decreased progressively from the southern to the northern areas. Along the east shore the average ranged from 42 meters (138 ft.) to 33 (108 ft.) and off the west shore from 39 (128 ft.) to 30 (98 ft.).

The bottom temperatures of 1930 and 1931 were compared for each month from June to August of the shallow and deep stations (excluding those in depths of 189-250 meters, i.e., 620-820 ft.) of each region. Since these detailed comparable records indicated no significant differences they were combined for all areas for each year. The monthly averages never varied more than 0.1° (0.18° F.) between the three months of the same year or the same month of both years. The combined records of all months were identical in the two years for the same waters--4.3° (39.7° F.) in the shallow and 4.0° (39.0° F.) in the deep waters. The grand averages of all data were identical (4.1° C; 39.4° F.) in 1930 and 1931.

Bottom temperatures of a region did not increase progressively in all waters with advance of the season during May-September. The few records indicated that in general the temperatures did rise in October and November. The combined data of each month also revealed no progressive trend through September in either the shallow or deep waters along the east or west

shore. The temperatures off both shores may, therefore, be combined as shown below. The number of records is shown in parentheses.

| Month | Shallow stations | | Deep stations | | All stations | |
|---|---|---|---|---|---|---|
| | C° | F° | C° | F° | C° | F° |
| May | 4.2(8) | 39.6 | 4.0(8) | 39.2 | 4.1(16) | 39.4 |
| June | 4.3(15) | 39.7 | 4.0(17) | 39.2 | 4.1(32) | 39.4 |
| July | 4.2(20) | 39.6 | 4.0(20) | 39.2 | 4.1(40) | 39.4 |
| August | 4.4(16) | 39.9 | 4.0(13) | 39.2 | 4.2(29) | 39.6 |
| September | 4.3(5) | 39.7 | 4.0(8) | 39.2 | 4.1(13) | 39.4 |
| October | -- | -- | 4.3(6) | 39.7 | 4.3(6) | 39.7 |
| November | 5.6(3) | 42.1 | 4.6(2) | 40.3 | 5.2(5) | 41.4 |
| May-September | 4.3(64) | 39.7 | 4.0(66) | 39.2 | 4.1(130) | 39.4 |
| October-November | 5.6(3) | 42.1 | 4.4(8) | 39.9 | 4.7(11) | 40.5 |

Proper comparisons indicated that the 1930 and 1931 records of all months from May to September and of all regions may be combined to ascertain the discrepancies between the bottom temperatures of the shallow and deep stations. The temperatures averaged 4.3° (39.7° F.) in the shallow waters that averaged 61 meters (200 ft.) and 4.0° (39.2° F.) in the deep waters with an average of 114 meters (374 ft.). The bottom temperatures actually declined gradually with increased depths as shown in the following table.

| Number of records | Depths | | Average temperatures | |
|---|---|---|---|---|
| | Meters | Feet | C° | F° |
| 9 | 40-49 | 131-161 | 4.43 | 39.97 |
| 27 | 50-59 | 164-194 | 4.36 | 39.85 |
| 14 | 60-69 | 197-226 | 4.23 | 39.61 |
| 21 | 70-89 | 230-292 | 4.18 | 39.52 |
| 30 | 90-109 | 295-358 | 4.02 | 39.24 |
| 8 | 110-119 | 361-390 | 3.96 | 39.13 |
| 4 | 120-129 | 394-423 | 3.95 | 39.11 |
| 4 | 130-139 | 426-456 | 3.88 | 38.98 |
| 9 | 140-149 | 459-489 | 3.86 | 38.95 |
| 7 | 150-189 | 492-620 | 3.91 | 39.04 |
| 4 | 220-250 | 722-820 | 3.62 | 38.52 |

Since no significant differences were observed between the average bottom temperatures of 1930 and 1931 and of the several months, they were combined to compare the data of various regions, although the depths of the waters had to be considered. The temperatures of depths beyond 185 meters (607 ft.) and of October and November were excluded. The trends were the same along both shores. Data of the opposite regions have, therefore, been combined as recorded below. The number of records is shown in parentheses. It appears that although the average bottom temperatures decreased consistently from south to north the discrepancies were small not exceeding 0.3° (0.54° F.).

## STATIONS IN UPPER LAKE MICHIGAN PROPER

Temperatures were obtained on 46 days in Upper Lake Michigan proper during June 3-September 12, 1932, and on three days during June 17-July 7, 1930 (table 9). The depths ranged from 32 to 79 meters (105 to 259 ft.) and averaged 64 meters (210 ft.) at 17 designated shallow stations and varied from 82 to 144 meters (269 to 472 ft.) and averaged 110 meters (361 ft.) at 23 deep stations. Surface temperatures recorded on the same day or two consecutive days showed differences between 2 deep or 2 shallow stations as great in a restricted section as in widely separated areas or as between shallow and deep waters during the same periods. The waters of the upper lake are, therefore, considered a unit throughout the period of observation with respect to temperatures.

During June 3-10 the surface temperatures rose from a minimum of 5.7° (42.3° F.) to 10.5° (50.9° F.); the average was 7.9° (46.2° F.). The limits of the other periods are based on the similarity of the temperatures. Only the average temperatures need to be compared. The average increased from 15.2° (59.4° F.) of the period June 14-July 14 to 18.0° (64.4° F.) during July 19-30, 19.7° (67.5° F.) during

| Regions | Shallow stations | | | | Deep stations | | | |
|---|---|---|---|---|---|---|---|---|
| | C° | F° | Meters | Feet | C° | F° | Meters | Feet |
| Southern | 4.5(18) | 40.1 | 58 | 190 | 4.1(18) | 39.4 | 96 | 315 |
| Middle | 4.3(19) | 39.7 | 62 | 203 | 4.0(24) | 39.2 | 114 | 374 |
| Northern | 4.2(27) | 39.6 | 62 | 203 | 3.9(27) | 39.0 | 131 | 430 |

Table 9.--Temperatures C° of Upper Lake Michigan proper, 1932. Data for stations 1 and 2 were obtained in 1930. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.
[C = cruise; D = maximum depths; S = surface]

| C9 Sta. G June 3 D 139 Air 15.5 | | C10 Sta. 230 June 6 D 102 Air 18.4 | | C10 Sta. 227 June 6 D 91 Air 20.3 | | C10 Sta. 226 June 9 D 123 Air 17.4 | | C11 Sta. 227 June 10 D 94 Air 16.2 | | C11 Sta. 227 June 10 D 68 Air 17.5 | | C11 Sta. 233 June 14 D 83 Air 23.1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 7.5 | S | 5.8 | S | 5.7 | S | 8.5 | S | 10.5 | S | 9.6 | S | 15.4 |
| 5 | 4.6 | 5 | 5.4 | 5 | 5.7 | 3 | 8.0 | 5 | 8.8 | 5 | 8.5 | 2 | 13.6 |
| 10 | 4.6 | 10 | 5.3 | 10 | 5.3 | 6 | 7.2 | 10 | 6.2 | 10 | 7.5 | 3 | 12.5 |
| 20 | 4.0 | 15 | 5.2 | 15 | 4.8 | 9 | 5.5 | 15 | 5.0 | 15 | 6.6 | 4 | 10.4 |
| 25 | 3.9 | 20 | 5.0 | 25 | 4.6 | 12 | 5.0 | 20 | 4.6 | 20 | 5.2 | 5 | 9.5 |
| 30 | 3.9 | 35 | 4.6 | 35 | 4.3 | 15 | 4.6 | 25 | 4.4 | 25 | 4.8 | 10 | 7.2 |
| 40 | 3.9 | 45 | 4.3 | 45 | 4.0 | 20 | 4.2 | 30 | 4.3 | 30 | 4.3 | 15 | 6.3 |
| 60 | 3.9 | 60 | 4.2 | 60 | 3.9 | 25 | 4.0 | 40 | 4.0 | 38 | 4.2 | 20 | 5.4 |
| 80 | 3.8 | 80 | 4.1 | 75 | 3.9 | 35 | 4.0 | 50 | 4.0 | 48 | 4.0 | 25 | 5.1 |
| 100 | 3.8 | 102 | 4.0 | 91 | 3.9 | 45 | 4.0 | 70 | 4.0 | 68 | 4.0 | 30 | 4.8 |
| 120 | 3.8 | | | | | 60 | 3.8 | 94 | 3.9 | | | 40 | 4.5 |
| 139 | ? | | | | | 80 | 3.8 | | | | | 60 | 4.2 |
| | | | | | | 100 | 3.8 | | | | | 83 | 4.0 |
| | | | | | | 123 | 3.8 | | | | | | |

| C11 Sta. 234 June 14 D 59 Air 26.4 | | C12 Sta. 228 June 15 D 97 Air 21.5 | | C12 Sta. 229 June 15 D 62 Air 18.7 | | C12 Sta. 235 June 16 D 139 Air 27.0 | | C12 Sta. 230 June 16 D 101 Air 21.2 | | C1 Sta. 2 June 17 D 78 Air -- | | C12 Sta. 231 June 17 D 96 Air 20.8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 15.6 | S | 14.0 | S | 14.6 | S | 19.0 | S | 16.4 | S | - | S | 18.0 |
| 3 | 12.6 | 5 | 8.7 | 2 | 13.5 | 2 | 14.5 | 3 | 11.2 | 6 | 7.8 | 2 | 13.9 |
| 6 | 10.2 | 10 | 7.4 | 5 | 10.0 | 4 | 11.0 | 6 | 9.4 | 16 | 6.5 | 4 | 10.7 |
| 10 | 9.0 | 15 | 5.4 | 10 | 7.4 | 6 | 9.8 | 10 | 7.8 | 26 | 6.0 | 6 | 9.0 |
| 15 | 7.6 | 20 | 4.7 | 15 | 5.2 | 9 | 8.4 | 15 | 5.7 | 36 | 5.2 | 8 | 8.9 |
| 20 | 7.1 | 25 | 4.4 | 20 | 4.7 | 12 | 7.0 | 20 | 4.8 | 46 | 4.6 | 10 | 7.8 |
| 25 | 6.0 | 30 | 4.4 | 30 | 4.6 | 14 | 6.8 | 30 | 4.4 | 56 | 4.2 | 15 | 5.4 |
| 30 | 5.4 | 37 | 4.0 | 40 | 4.4 | 17 | 5.4 | 40 | 4.0 | 78 | 4.0 | 20 | 4.8 |
| 40 | 4.5 | 57 | 4.0 | 50 | 4.2 | 20 | 4.8 | 60 | 4.0 | | | 26 | 4.2 |
| 59 | 4.2 | 58 | 4.0 | 62 | 4.2 | 25 | 4.4 | 80 | 4.0 | | | 36 | 4.0 |
| | | 77 | 4.0 | | | 30 | 4.0 | 101 | 3.9 | | | 46 | 4.0 |
| | | 97 | 3.9 | | | 40 | 4.0 | | | | | 56 | 4.0 |
| | | | | | | 60 | 4.0 | | | | | 76 | 4.0 |
| | | | | | | 80 | 4.0 | | | | | 96 | 4.0 |
| | | | | | | 100 | 4.0 | | | | | | |
| | | | | | | 139 | 3.9 | | | | | | |

| C2 Sta. 2 June 26 D 65 Air 14.8 | | C2 Sta. 1 June 26 D 102 Air -- | | C13 Sta. 236 June 27 D 123 Air 19.8 | | C13 Sta. 233 June 27 D 82 Air 15.7 | | C13 Sta. 232 June 29 D 96 Air 18.8 | | C13 Sta. 235 June 30 D 128 Air 16.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 11.8 | S | 13.7 | S | 14.7 | S | 13.9 | S | 14.7 | S | 14.8 |
| 4 | 11.2 | 2 | 13.2 | 5 | 13.3 | 4 | 12.9 | 4 | 14.2 | 3 | 13.7 |
| 9 | 11.0 | 7 | 12.5 | 10 | 12.1 | 8 | 11.8 | 7 | 14.1 | 6 | 13.6 |
| 14 | 8.1 | 10 | 8.5 | 15 | 11.0 | 12 | 11.6 | 10 | 13.7 | 9 | 13.5 |
| 17 | 6.3 | 12 | 8.1 | 16 | 10.0 | 16 | 9.1 | 12 | 12.4 | 12 | 12.7 |
| 20 | 5.9 | 17 | 6.1 | 18 | 7.9 | 20 | 6.0 | 13 | 9.0 | 14 | 9.4 |
| 25 | 5.5 | 22 | 5.9 | 20 | 6.8 | 25 | 5.2 | 14 | 8.4 | 16 | 9.0 |
| 35 | 5.5 | 32 | 5.2 | 25 | 4.8 | 30 | 4.7 | 15 | 7.6 | 18 | 8.2 |
| 65 | 4.7 | 52 | 4.9 | 30 | 4.5 | 40 | 4.3 | 20 | 6.8 | 20 | 7.9 |
| | | 102 | 4.0 | 35 | 4.2 | 60 | 4.1 | 25 | 5.2 | 25 | 6.7 |
| | | | | 55 | 4.0 | 82 | 4.0 | 30 | 4.8 | 30 | 5.2 |
| | | | | 75 | 4.0 | | | 35 | 4.6 | 40 | 4.3 |
| | | | | 100 | 3.9 | | | 45 | 4.2 | 50 | 4.2 |
| | | | | 123 | 3.9 | | | 60 | 4.0 | 60 | 4.0 |
| | | | | | | | | 76 | 4.0 | 80 | 4.0 |
| | | | | | | | | 96 | 4.0 | 100 | 4.0 |
| | | | | | | | | | | 128 | 4.0 |

Table 9.--Temperatures C° of Upper Lake Michigan proper, 1932. Data for stations 1 and 2 were obtained in 1930. Cont'd.

| C14 Sta. 236 July 5 D 118 Air 14.8 | C3 Sta. 1 July 7 D 101 Air 17.9 | C14 Sta. 232 July 7 D 75 Air 19.4 | C14 Sta. 235 July 8 D 66 Air 19.8 | C15 Sta. 236 July 9 D 132 Air 22.6 | C15 Sta. 237 July 9 D 107 Air 18.8 | C15 Sta. 232 July 12 D 106 Air 16.7 |
|---|---|---|---|---|---|---|
| S 13.4 | S 14.0 | S 14.6 | S 14.2 | S 15.0 | S 14.5 | S 15.2 |
| 5 13.0 | 5 14.0 | 1 14.6 | 3 14.0 | 5 14.6 | 5 14.0 | 5 15.0 |
| 10 12.9 | 10 13.2 | 6 14.4 | 5 13.8 | 10 13.7 | 10 13.6 | 10 14.5 |
| 14 12.8 | 12 11.1 | 11 11.9 | 8 13.6 | 15 12.4 | 14 11.9 | 15 12.1 |
| 17 12.6 | 15 9.1 | 14 10.9 | 13 10.8 | 18 11.8 | 18 10.2 | 18 11.2 |
| 20 12.6 | 21 6.6 | 17 10.2 | 18 8.1 | 21 10.9 | 21 9.5 | 21 9.4 |
| 25 11.7 | 29 6.1 | 20 9.4 | 21 7.4 | 24 8.5 | 24 8.8 | 24 8.7 |
| 30 5.3 | 39 5.6 | 23 7.4 | 24 6.5 | 27 6.8 | 27 7.6 | 27 7.4 |
| 40 4.2 | 59 4.7 | 25 7.0 | 27 5.8 | 30 5.7 | 30 5.8 | 30 6.4 |
| 50 4.0 | 99 4.2 | 30 6.0 | 30 5.3 | 35 4.6 | 35 4.3 | 35 5.6 |
| 70 4.0 | 101 4.2 | 35 5.2 | 40 4.5 | 40 4.3 | 40 4.3 | 40 5.1 |
| 90 3.9 | | 50 4.6 | 50 4.5 | 60 3.9 | 50 4.0 | 60 4.4 |
| 118 3.9 | | 75 4.0 | 66 4.3 | 80 3.9 | 70 4.0 | 80 4.2 |
| | | | | 100 3.9 | 87 4.0 | 106 4.0 |
| | | | | 132 3.9 | 107 3.9 | |

| C15 Sta. 235 July 13 D 130 Air 22.8 | C16 Sta. 238 July 14 D 93 Air 19.2 | C16 Sta. 242 July 19 D 79 Air 24.0 | C18 Sta. 243 July 27 D 100 Air 17.2 | C18 Sta. 245 July 28 D 75 Air 20.2 | C18 Sta. 241 July 30 D 49 Air 22.2 | C19 Sta. 248 Aug. 1 D 119 Air 23.0 |
|---|---|---|---|---|---|---|
| S 14.5 | S 15.4 | S 18.2 | S 16.8 | S 18.6 | S 18.5 | S 19.6 |
| 5 14.0 | 5 15.2 | 4 17.4 | 3 16.7 | 5 18.6 | 5 18.2 | 5 19.2 |
| 10 14.0 | 10 15.2 | 7 17.4 | 6 16.6 | 10 18.4 | 10 17.8 | 10 19.0 |
| 14 13.6 | 14 14.8 | 10 17.2 | 9 16.5 | 15 17.9 | 13 17.8 | 12 19.0 |
| 18 9.6 | 17 14.4 | 13 16.6 | 12 16.5 | 18 15.3 | 16 17.7 | 15 17.8 |
| 21 8.4 | 20 13.4 | 14 16.2 | 15 16.4 | 21 13.0 | 19 17.6 | 18 17.4 |
| 24 8.2 | 23 12.3 | 15 14.0 | 18 14.2 | 24 11.1 | 22 17.3 | 21 15.7 |
| 27 7.5 | 25 10.4 | 16 12.2 | 19 9.8 | 27 9.2 | 24 13.5 | 22 11.8 |
| 30 6.7 | 28 9.4 | 18 10.0 | 21 9.4 | 30 8.1 | 25 13.2 | 24 10.5 |
| 35 5.8 | 30 8.5 | 20 7.9 | 24 8.8 | 35 7.6 | 29 12.0 | 26 9.9 |
| 40 4.8 | 33 7.6 | 22 7.8 | 27 8.0 | 40 6.3 | 32 8.4 | 31 7.5 |
| 50 4.4 | 43 5.4 | 24 6.9 | 30 7.0 | 50 5.6 | 39 6.9 | 41 5.4 |
| 60 4.0 | 53 4.5 | 29 5.5 | 35 6.1 | 60 5.2 | 49 4.7 | 76 4.3 |
| 80 4.0 | 73 4.0 | 34 5.2 | 45 5.1 | 75 4.8 | | 91 4.1 |
| 100 4.0 | 93 4.0 | 44 5.0 | 60 4.5 | | | 119 4.0 |
| 130 4.0 | | 54 4.5 | 80 4.2 | | | |
| | | 64 4.5 | 100 4.0 | | | |
| | | 79 4.5 | | | | |

| C19 Sta. 250 Aug. 2 D 65 Air 21.9 | C19 Sta. 241 Aug. 4 D 58 Air 23.9 | C20 Sta. 249 Aug. 5 D 114 Air 22.5 | C20 Sta. 251 Aug. 6 D 114 Air 23.4 | C20 Sta. 246 Aug. 8 D 76 Air 20.0 |
|---|---|---|---|---|
| S 19.5 | S 19.2 | S 19.2 | S 20.1 | S 19.4 |
| 5 19.5 | 5 19.2 | 5 19.0 | 5 19.7 | 5 19.4 |
| 10 19.4 | 10 18.8 | 10 18.9 | 10 19.6 | 10 19.4 |
| 13 19.4 | 15 18.3 | 15 18.7 | 15 19.5 | 15 19.4 |
| 18 18.5 | 20 17.4 | 20 18.4 | 19 17.3 | 18 17.3 |
| 21 16.5 | 23 16.0 | 27 17.8 | 21 12.8 | 21 13.7 |
| 24 12.7 | 26 14.7 | 29 15.4 | 23 11.0 | 23 10.8 |
| 25 10.6 | 29 12.8 | 31 12.2 | 25 9.4 | 25 9.7 |
| 26 8.7 | 32 11.0 | 33 10.6 | 27 9.1 | 27 9.2 |
| 27 8.4 | 33 10.5 | 35 8.3 | 29 7.9 | 30 8.0 |
| 30 6.2 | 35 8.3 | 40 6.3 | 31 7.2 | 35 6.8 |
| 35 5.4 | 40 6.1 | 50 5.0 | 33 6.9 | 40 5.8 |
| 40 5.0 | 50 5.2 | 65 4.5 | 35 6.8 | 50 4.9 |
| 50 4.5 | 58 4.8 | 90 4.2 | 40 6.0 | 76 4.5 |
| 65 4.2 | | 114 4.1 | 50 5.1 | |
| | | | 65 4.5 | |
| | | | 90 4.0 | |
| | | | 114 4.0 | |

Table 9.--Temperatures C° of Upper Lake Michigan proper, 1932. Data for stations 1 and 2 were obtained in 1930. Cont'd.

| C20 | C20 | C21 | C21 | C21 | C21 | C22 |
|---|---|---|---|---|---|---|
| Sta. 255 | Sta. 252 | Sta. 253 | Sta. 254 | Sta. 255 | Sta. 252 | Sta. 257 |
| Aug. 8 | Aug. 9 | Aug. 10 | Aug. 11 | Aug. 12 | Aug. 13 | Aug. 15 |
| D 48 | D 78 | D 118 | D 144 | D 32 | D 70 | D 48 |
| Air 24.6 | Air 22.9 | Air 20.6 | Air 24.4 | Air 23.4 | Air -- | Air 22.2 |
| S 21.0 | S 19.7 | S 20.8 | S 20.4 | S 20.0 | S 20.3 | S 20.8 |
| 6 20.5 | 5 19.2 | 5 20.0 | 5 20.1 | 6 20.0 | 5 19.8 | 5 20.5 |
| 12 19.6 | 10 19.2 | 10 19.7 | 10 19.7 | 12 19.0 | 10 19.8 | 10 20.0 |
| 17 19.6 | 15 19.0 | 15 18.8 | 15 19.6 | 16 18.7 | 15 19.7 | 15 19.2 |
| 19 19.3 | 17 18.6 | 17 18.5 | 17 19.0 | 19 18.0 | 17 18.9 | 16 19.0 |
| 21 19.3 | 19 14.5 | 19 17.6 | 19 17.4 | 21 17.6 | 19 16.8 | 18 13.5 |
| 23 19.0 | 21 13.4 | 21 15.8 | 21 14.8 | 23 15.8 | 21 13.1 | 20 11.0 |
| 24 15.9 | 23 10.6 | 23 13.1 | 23 14.6 | 25 15.1 | 23 9.8 | 24 9.3 |
| 26 15.2 | 25 8.0 | 25 12.1 | 25 14.6 | 27 14.2 | 25 8.5 | 26 8.8 |
| 28 15.0 | 27 7.6 | 27 11.9 | 27 13.5 | 29 9.4 | 27 8.3 | 28 8.5 |
| 33 12.5 | 30 7.2 | 28 9.8 | 30 11.8 | 32 9.0 | 30 7.6 | 30 8.1 |
| 38 9.8 | 35 5.6 | 30 8.4 | 35 8.7 | | 35 6.4 | 33 7.6 |
| 48 7.4 | 40 5.0 | 40 6.0 | 40 7.5 | | 40 5.5 | 38 7.4 |
| | 50 4.4 | 50 5.0 | 50 5.7 | | 50 4.7 | 48 7.0 |
| | 60 4.3 | 70 4.5 | 60 4.5 | | 70 4.0 | |
| | 78 4.0 | 90 4.1 | 75 4.1 | | | |
| | | 118 4.0 | 100 4.0 | | | |
| | | | 144 4.0 | | | |

| C22 | C22 | C23 | C23 | C23 | C25 | C25 |
|---|---|---|---|---|---|---|
| Sta. 253 | Sta. 254 | Sta. 260 | Sta. 267 | Sta. 257 | Sta. 267 | Sta. 259 |
| Aug. 16 | Aug. 17 | Aug. 20 | Aug. 22 | Aug. 23 | Sept. 1 | Sept. 2 |
| D 60 | D 65 | D 55 | D 86 | D 77 | D 87 | D 118 |
| Air 22.6 | Air 23.1 | Air 20.8 | Air 19.5 | Air 22.0 | Air 24.2 | Air 24.4 |
| S 20.6 | S 21.0 | S 18.0 | S 19.4 | S 19.6 | S 20.5 | S 20.0 |
| 5 20.5 | 5 20.7 | 5 17.9 | 5 19.2 | 5 19.1 | 5 20.0 | 5 19.9 |
| 10 20.4 | 10 20.5 | 10 17.8 | 10 18.7 | 10 18.6 | 10 19.8 | 10 19.8 |
| 13 19.4 | 15 19.4 | 15 17.8 | 15 18.5 | 15 17.8 | 14 18.6 | 15 19.8 |
| 15 18.0 | 17 19.1 | 18 17.1 | 17 18.5 | 17 16.4 | 16 18.4 | 20 19.0 |
| 17 14.6 | 19 18.2 | 21 16.6 | 19 18.5 | 19 15.6 | 18 18.0 | 22 18.8 |
| 19 13.0 | 21 16.8 | 23 14.3 | 21 15.6 | 21 13.5 | 20 16.0 | 24 18.8 |
| 21 10.4 | 23 15.4 | 25 11.4 | 23 11.2 | 23 11.2 | 22 12.1 | 26 16.4 |
| 23 8.6 | 25 13.0 | 27 10.4 | 25 10.0 | 25 9.6 | 24 11.2 1/ | 28 13.1 |
| 25 7.0 | 27 9.7 | 30 8.5 | 27 9.3 | 27 8.9 | 26 9.4 | 30 10.9 |
| 27 6.6 | 30 7.8 | 35 7.2 | 29 8.8 | 29 8.4 | 28 8.2 | 35 7.9 |
| 30 6.2 | 35 6.4 | 45 5.7 | 32 7.8 | 32 8.0 | 30 7.8 | 40 6.9 |
| 35 5.4 | 40 6.0 | 50 5.3 | 35 6.8 | 35 7.6 | 32 7.6 | 50 5.4 |
| 40 5.0 | 50 5.4 | 55 4.9 | 40 5.8 | 40 7.3 | 35 6.4 | 70 4.4 |
| 50 4.6 | 65 4.9 | | 50 4.8 | 50 7.0 | 40 5.5 | 90 4.1 |
| 60 4.2 | | | 60 4.4 | 60 6.8 | 50 4.5 | 118 4.0 |
| | | | 86 4.0 | 77 6.6 | 60 4.2 | |
| | | | | | 87 4.0 | |

| C25 | C26 | C26 | C26 | C27 |
|---|---|---|---|---|
| Sta. 266 | Sta. 267 | Sta. 259 | Sta. 266 | Sta. 263 |
| Sept. 3 | Sept. 7 | Sept. 9 | Sept. 10 | Sept. 12 |
| D 118 | D 102 | D 118 | D 119 | D 105 |
| Air 22.6 | Air 17.3 | Air 22.7 | Air 21.2 | Air 24.5 |
| S 19.7 | S 18.6 | S 19.0 | S 19.0 | S 19.6 |
| 5 19.6 | 5 18.5 | 8 18.6 | 8 18.8 | 5 19.6 |
| 10 19.6 | 10 18.5 | 18 18.6 | 15 18.8 | 10 19.6 |
| 14 19.4 | 15 18.4 | 24 18.5 | 19 18.7 | 15 19.4 |
| 16 19.4 | 18 18.4 | 26 18.5 | 21 16.5 | 20 19.3 |
| 20 18.4 | 21 17.0 | 30 10.1 | 23 14.4 | 24 18.6 |
| 22 17.0 | 23 11.8 | 35 8.4 | 25 12.0 | 26 16.7 |
| 24 15.2 | 25 9.8 | 40 8.0 | 26 10.8 | 28 13.2 |
| 26 11.7 | 27 9.2 | 60 5.3 | 30 9.6 | 30 10.8 |
| 28 10.8 | 30 7.6 | 80 5.0 | 35 7.8 | 35 7.8 |
| 30 10.9 | 35 6.3 | 118 4.4 | 40 6.4 | 45 6.8 |
| 35 8.3 | 45 5.1 | | 50 4.8 | 60 5.6 |
| 40 7.1 | 60 4.5 | | 70 4.4 | 80 4.5 |
| 50 5.5 | 80 4.2 | | 90 4.1 | 105 4.5 |
| 70 4.6 | 102 4.2 | | 119 4.0 | |
| 90 4.3 | | | | |
| 118 4.2 | | | | |

1/ Probably a second thermocline at 24 - 26; 11.2° - 9.4°.

August 1-9, to 20.6° (69.1° F.) during August 10-17, and then decreased to 19.3° (66.7° F.) during August 20-September 12. The maximum was 21.0° (69.8° F.) recorded on August 8 and 17.

Most of the subsurface temperatures (81 percent) followed the direction of change of the surface temperatures, some (32 percent) at all depths to the bottom but the vast majority (68 percent) down to varying depths from about 4 to 35 meters (13 to 115 ft.). The temperatures of the waters below these upper levels either shifted in contrast to the surface temperatures (76 percent) or remained constant (24 percent). In a few instances the temperatures of the lowest levels were again reversed.

A temperature of 5° (41° F.) lowered gradually with the advance of the season although occasionally it descended rather suddenly beyond the general level of the period. This 5-degree temperature descended from about 4 meters (13 ft.) on June 3 to lower levels, reaching depths just below 20 meters (66 ft.) by the middle of June. These depths averaged 18.4 meters (60 ft.). This temperature continued to descend to depths that ranged, excluding one or two extremes, from 25 to 35 meters (82 to 115 ft.) with an average of 31.6 meters (104 ft.) during June 27-July 9, from 40 to 55 meters (131 to 180 ft.) with an average of 48.8 meters (160 ft.) during July 12-September 1, and from 50 to 80 meters (164 to 262 ft.) with an average of 60.8 meters (200 ft.) during September 2-12.

A temperature of 10° (50° F.) was not recorded until June 10 near the surface. It then descended gradually from an average of 5.1 meters (17 ft.) during June 14-17 to an average of 16.3 meters (54 ft.) during June 27-July 8, to 20.1 (66 ft.) during July 9-27, to 27 (89 ft.) during July 28-September 1, and to 29.3 (96 ft.) during September 2-12.

Temperatures below 4.0° (39.2° F.) were recorded until July 9 only at stations deeper than 90 meters (295 ft.). The minimum temperature of 3.8° (38.8° F.) was reported only on June 3 and 9 at depths of 60 meters (197 ft.) and beyond. Bottom temperature did not exceed 4.0° (39.2° F.) in depths greater than 82 meters (269 ft.) with one exception (August 5) until September 2, 1932, when thereafter they ranged from 4.0° to 4.5° (39.2° to 40.1° F.) and averaged 4.3° (39.7° F.). In the water less than 80 meters (262 ft.) the 1932 temperatures varied from 4.0° to 4.3° (39.2° to 39.7° F.) with an average of 4.1° (39.4° F.) through July 8. From July 19 to August 20 they ranged from 4.0° to 4.9° (39.2° to 40.8° F.) and averaged 4.5° (40.1° F.) excluding the high temperatures recorded at the isolated stations (255, 257) about 20 miles northeast of Charlevoix. Their August bottom temperatures varied from 6.6° to 9.0° (43.9° to 48.2° F.) and averaged 7.5° (45.5° F.).

The waters did not warm up enough in 1932 to develop a thermocline until June 14. It did not extend much beyond 5 meters (16 ft.) until at least after June 17. It was usually found between 12 and 20 meters (39 and 66 ft.) during June 27-July 27 and between 18 and 30 meters (59 and 98 ft.) during July 30-September 12. The thermocline was at times eliminated at widely separated stations particularly during July 7-12. It did, however, persist after July. No differences were observed between shallow and deep stations with respect to the depths and disappearance of thermoclines during the same period. Double thermoclines occurred on five dates between July 28 and August 17 at 1 deep and 4 shallow stations at depths between 14 and 33 meters (46 and 108 ft.).

It is of interest to note that the temperatures of the thermoclines also tended to change with the advance of the season. The minimum and maximum temperatures of the thermoclines of June 14-17 that had formed in the upper 5 meters (16 ft.) averaged 10.5° and 16.1° (50.9° and 61.0° F.). As the thermocline descended the averages at first decreased to 8.6° and 12.3° (47.5° and 54.1° F.) (June 27-July 14), then slowly rose to 9.2° and 15.1° (48.6° and 59.2° F.) (July 19-August 4) and to 11.0° and 17.6° (51.8° and 63.7° F.) (August 5-September 12). The thermal gradients ranged from 2° to 10° (4° to 18° F.) and covered depth intervals that varied from 1 to 8 meters (3 to 26 ft.). During the above four periods between June 14 and September 12 the averages were respectively 5.6° (10° F.) and 4.1 meters (14 ft.), 3.5° (6° F.) and 2.7 meters (9 ft.), 5.7° (10° F.) and 3.3 meters (11 ft.), and 6.4° (12° F.) and 4.3 meters (14 ft.). It may also

be mentioned that the few records indicate that midsummer temperatures of the upper waters not beyond 30 meters (98 ft.) were lower in 1930 than in 1932.

## STATIONS IN GREEN BAY

Eight series of temperatures were taken in Green Bay on 8 days at 5 stations during September 21-October 4, 1930, and 31 on 24 days at 24 stations during April 19-June 13, 1932 (table 10). The depths ranged from 30 to 43 meters (98 to 141 ft.) in the midsection in 1930, except at station 46 where the water was only 19 meters (62 ft.) deep. They averaged 32 meters (105 ft.). In 1932 the depths varied from 24 to 35 meters (79 to 115 ft.) with an average of 29 meters (95 ft.) in the central section and from 31 to 46 meters (102 to 151 ft.) in the upper region with an average of 38 meters (125 ft.).

Surface temperatures taken on the same day or two consecutive days showed no greater differences between the northern and southern areas than in either one of these sections during the same time of year. All of Green Bay waters were, therefore, treated as a unit, although the northern waters did not seem to warm as fast as the southern waters as indicated, for example, by the records of May 9 and 10 and 12 and 13. Although the generally greater depths of the northern stations may have accounted for the slower rise of temperatures, this factor was not responsible for the differences of the temperatures on May 12 and 13 because the depths of both stations were identical. Perhaps the location of a station may have been the dominant factor. The 1932 records will be considered first.

The temperatures of April 19, 1932, ranged from 1.0° (33.8° F.) at the bottom, the lowest recorded, to 1.2° (34.2° F.) at the surface. The temperatures in general increased gradually with the advance of the season to June 13, 1932, the last day. It is noticed that they did not consistently change gradually from the bottom to the surface until May 13. The irregular subsurface temperatures probably resulted from the inflow at different levels of the several tributary waters.

None of the temperatures exceeded 2.0° (35.6° F.) until April 27, 3.0° (37.4° F.) until May 3, and 4.0° (39.2° F.) until May 10. The differences between the bottom and surface temperatures of this period averaged 0.2° (0.36° F.), only once exceeding 0.3° (0.54° F.). As the temperatures above 4.0° (39.2° F.) started to rise the differences between those of the bottom and surface also increased due to the changes at the upper levels. Five-degree (41° F.) water appeared first on May 11 in central Green Bay between depths of 5 and 10 meters (16 and 33 ft.) and below 15 meters (49 ft.), but by May 17 it had already been exceeded at all depths.

The surface temperature rose quite regularly from 1.2° (34.2° F.) on April 19 to the maximum of 17.6° (63.7° F.) on June 13. The subsurface temperatures followed with only three exceptions the direction of change of the surface temperatures. At almost all stations the shifting took place down to the bottom. Virtually all of the decreases involved the records of the upper region. However, when comparisons were confined to this region then the data show that most of the temperatures had risen with the advance of the season. The bottom temperature also increased quite regularly from 1.0° (33.8° F.) on April 19 until it reached 6.6° (43.9° F.) on May 23 when it was not exceeded thereafter.

A thermocline did not develop until June 8 in northern Green Bay at the deeper of two stations when the temperature dropped from 11.3° (52.3° F.) to 8.2° (46.8° F.) at depths of 9 to 10 meters (30 to 33 ft.). However, in the same area the thermocline apparently had been eliminated on June 9 but reappeared on June 13 nearer the surface at depths of 2 to 8 meters (7 to 26 ft.) and at higher temperatures that ranged from 10.6° to 16.8° (51.1° to 62.2° F.).

It may be mentioned incidentally that the surface waters of Green Bay warmed much more rapidly than those of Upper Lake Michigan as indicated by the difference of 4.1° (7.4° F.) between their averages of the period June 6-14.

The 1930 autumn records of Green Bay showed that the surface temperatures of October had decreased to the same level of those of early June in 1932. The average declined from 16.2° (61.2° F.) during September 21-25 to 13.0° (55.4° F.) during September 30-October 4. The fall subsurface

Table 10.--Temperatures C° of Green Bay, 1930 and 1932. Station (Sta.) numbers under 100 were occupied in 1930; those over 200 in 1932. Depths (D) are recorded in meters. Locations of the stations are shown in table 1 and on the map. Thermoclines are indicated between two horizontal lines.

[C = cruise; D = maximum depths; S = surface]

| C8 Sta. 40 Sept. 21 D 32 | C8 Sta. 44 Sept. 23 D 32 | C8 Sta. 46 Sept. 24 D 19 | C8 Sta. 44 Sept. 25 D 30 | C8 Sta. 47 Sept. 30 D 32 | C8 Sta. 48 Oct. 1 D 43 | C8 Sta. 48 Oct. 3 D 40 |
|---|---|---|---|---|---|---|
| Air 18.8 | Air 19.2 | Air 20.4 | Air 18.0 | Air 11.4 | Air 12.2 | Air 12.8 |
| S 15.9 | S 16.5 | S 15.5 | S 16.8 | S 12.0 | S 13.5 | S 14.0 |
| 2 16.1 | 4 16.4 | 2 15.3 | 2 16.8 | 4 12.0 | 4 12.9 | 2 12.8 |
| 4 16.1 | 7 16.3 | 4 15.3 | 4 16.6 | 7 12.0 | 7 12.9 | 5 12.8 |
| 7 16.0 | 10 16.3 | 6 15.2 | 7 16.5 | 10 12.0 | 10 12.8 | 8 12.5 |
| 10 16.0 | 13 15.8 | 8 14.9 | 10 16.4 | 13 11.6 | 13 12.8 | 11 12.5 |
| 13 16.0 | 16 14.9 | 10 12.3 | 13 16.0 | 16 11.5 | 16 12.7 | 14 12.5 |
| 16 14.6 | 19 13.8 | 13 9.7 | 16 15.3 | 19 11.5 | 19 12.6 | 17 12.3 |
| 19 11.2 | 22 11.9 | 16 9.4 | 19 10.2 | 22 11.4 | 22 11.6 | 20 12.2 |
| 22 10.7 | 25 8.9 | 19 9.4 | 22 9.2 | 25 11.4 | 25 11.4 | 23 11.1 |
| 25 10.2 | 32 8. 6 | | 25 8.8 | 32 11.4 | 30 10.5 | 33 9.4 |
| 32 8.8 | | | 30 8.5 | | 43 9.9 | 40 8.6 |

| C8 Sta. 47 Oct. 4 D 30 | C1 Sta. 201 Apr. 19 D 30 | C1 Sta. 202 Apr. 20 D 31 | C1 Sta. 203 Apr. 20 D 31 | C2 Sta. 204 Apr. 21 D 28 | C2 Sta. 205 Apr. 22 D 28 | C2 Sta. 206 Apr. 22 D 32 |
|---|---|---|---|---|---|---|
| Air 13.8 | Air 12.7 | Air 6.0 | Air 4.9 | Air 6.8 | Air 8.5 | Air 8.9 |
| S 12.6 | S 1.2 | S 1.0 | S 1.5 | S 1.7 | S 1.7 | S 2.0 |
| 4 12.5 | 5 1.2 | 5 1.2 | 5 1.3 | 3 1.5 | 10 1.5 | 5 1.9 |
| 7 12.4 | 10 1.1 | 10 1.2 | 10 1.3 | 8 1.5 | 15 1.5 | 10 2.0 |
| 10 12.1 | 15 1.0 | 20 1.3 | 20 1.3 | 13 1.5 | 20 1.6 | 15 1.7 |
| 13 12.0 | 20 1.0 | 31 1.4 | 31 1.4 | 20 1.5 | 28 1.6 | 20 1.8 |
| 16 11.4 | 25 1.0 | | | 28 1.5 | | 25 1.9 |
| 19 11.4 | 30 1.0 | | | | | 32 2.0 |
| 22 11.3 | | | | | | |
| 25 11.3 | | | | | | |
| 30 10.2 | | | | | | |

| C3 Sta. 208 Apr. 27 D 29 | C3 Sta. 206 Apr. 28 D 32 | C3 Sta. 209 Apr. 29 D 25 | C3 Sta. 210 May 2 D 31 | C4 Sta. 211 May 3 D 26 | C4 Sta. 214 May 5 D 27 |
|---|---|---|---|---|---|
| Air 9.9 | Air 16.9 | Air 12.5 | Air 12.5 | Air 10.3 | Air 9.2 |
| S 2.3 | S 2.5 | S 2.8 | S 3.0 | S 4.0 | S 3.8 |
| 5 2.2 | 5 2.5 | 5 2.8 | 2 3.0 | 5 3.9 | 3 3.7 |
| 10 2.2 | 10 2.5 | 10 2.5 | 5 2.9 | 10 3.8 | 6 3.8 |
| 15 2.2 | 15 2.4 | 15 2.6 | 8 2.9 | 15 3.8 | 9 3.8 |
| 20 2.1 | 20 2.4 | 20 2.6 | 11 2.9 | 20 3.8 | 12 3.5 |
| 25 2.1 | 25 2.5 | 25 2.7 | 16 2.8 | 26 3.8 | 17 3.5 |
| 29 2.1 | 32 2.7 | | 21 2.8 | | 22 3.6 |
| | | | 26 2.8 | | 27 3.8 |
| | | | 31 2.9 | | |

Table 10.--Temperatures C° of Green Bay, 1930 and 1932. Cont'd.

| C4 | C5 | C5 | C5 | C5 | C6 | C6 |
|---|---|---|---|---|---|---|
| Sta. 216 | Sta. 212 | Sta. 215 | Sta. 213 | Sta. 217 | Sta. 212 | Sta. 218 |
| May 9 | May 10 | May 11 | May 12 | May 13 | May 17 | May 17 |
| D 34 | D 25 | D 25 | D 35 | D 35 | D 24 | D 32 |
| Air 8.1 | Air 10.7 | Air 11.9 | Air 15.1 | Air 16.1 | Air 14.6 | Air 14.5 |
| S 3.6 | S 4.2 | S 5.1 | S 5.6 | S 4.8 | S 8.3 | S 6.6 |
| 5 3.6 | 5 4.2 | 5 5.1 | 5 5.0 | 5 4.1 | 5 7.0 | 4 6.6 |
| 10 3.6 | 10 4.0 | 10 4.9 | 10 4.8 | 10 4.0 | 10 6.5 | 8 6.1 |
| 15 3.6 | 15 4.1 | 15 4.9 | 15 4.6 | 15 4.0 | 15 5.9 | 12 5.9 |
| 20 3.5 | 20 4.2 | 20 5.0 | 20 4.4 | 20 3.8 | 20 5.8 | 16 5.9 |
| 25 3.5 | 25 4.2 | 25 5.0 | 25 4.2 | 25 3.8 | 24 5.8 | 20 5.8 |
| 30 3.5 | | | 30 4.2 | 30 3.8 | | 24 5.8 |
| 34 3.5 | | | 35 4.3 | 25 3.8 | | 28 5.8 |
| | | | | | | 32 5.6 |

| C6 | C6 | C7 | C7 | C7 | C7 | C7 |
|---|---|---|---|---|---|---|
| Sta. 219 | Sta. 221 | Sta. 218 | Sta. 222 | Sta. 219 | Sta. 220 | Sta. 223 |
| May 18 | May 23 | May 23 | May 23 | May 24 | May 25 | May 25 |
| D 28 | D 31 | D 32 | D 31 | D 29 | D 32 | D 35 |
| Air 22.3 | Air 15.4 | Air 18.9 | Air 18.1 | Air 15.8 | Air 15.2 | Air 22.3 |
| S 6.8 | S 6.8 | S 10.2 | S 8.5 | S 8.1 | S 8.0 | S 7.7 |
| 2 6.8 | 4 6.6 | 4 9.3 | 4 8.4 | 5 8.1 | 4 8.0 | 4 7.6 |
| 4 6.6 | 7 6.6 | 7 8.1 | 7 7.1 | 9 8.0 | 8 7.4 | 8 7.1 |
| 8 6.6 | 10 6.5 | 10 8.0 | 10 7.1 | 13 7.3 | 12 7.3 | 12 7.0 |
| 12 6.5 | 15 6.4 | 13 7.7 | 13 7.0 | 17 7.1 | 16 6.6 | 16 6.6 |
| 16 6.2 | 20 6.3 | 16 7.6 | 16 7.0 | 21 6.8 | 20 5.8 | 20 5.8 |
| 20 6.1 | 25 6.2 | 19 7.6 | 19 7.0 | 25 6.6 | 24 5.7 | 24 5.5 |
| 24 6.1 | 31 6.0 | 22 7.1 | 22 6.8 | 29 6.5 | 28 5.5 | 28 5.5 |
| 28 6.0 | | 25 7.0 | 25 6.6 | | 32 5.5 | 32 5.4 |
| | | 28 6.7 | 28 6.6 | | | 35 5.4 |
| | | 32 6.5 | 31 6.6 | | | |

| C7 | C10 | C10 | C10 | C11 |
|---|---|---|---|---|
| Sta. 224 | Sta. 223 | Sta. 225 | Sta. 224 | Sta. 225 |
| May 25 | June 8 | June 8 | June 9 | June 13 |
| D 41 | D 31 | D 45 | D 44 | D 46 |
| Air 20.9 | Air 23.1 | Air 21.3 | Air 16.8 | Air 19.5 |
| S 7.6 | S 12.3 | S 13.1 | S 14.3 | S 17.6 |
| 5 7.6 | 2 12.3 | 2 12.4 | 4 11.8 | 2 16.8 |
| 10 7.1 | 4 11.8 | 5 12.0 | 7 11.3 | 5 13.8 |
| 15 6.5 | 8 9.8 | 7 11.9 | 10 9.6 | 8 10.6 |
| 20 5.6 | 12 8.0 | 9 11.3 | 15 7.8 | 12 8.6 |
| 25 5.6 | 16 7.0 | 10 8.2 | 20 7.4 | 16 7.4 |
| 30 5.3 | 20 6.6 | 15 7.4 | 24 7.0 | 20 7.0 |
| 35 5.2 | 25 6.6 | 20 6.9 | 34 6.5 | 25 6.6 |
| 41 5.2 | 31 6.6 | 25 6.6 | 44 6.4 | 30 6.5 |
| | | 35 6.3 | | 36 6.4 |
| | | 45 6.2 | | 46 6.4 |

| Month | 1930 C° | 1930 F° | 1932 C° | 1932 F° | 1931 C° | 1931 F° | 1932 C° | 1932 F° |
|---|---|---|---|---|---|---|---|---|
| June | 10.5 (8) | 50.9 | 15.9 (7) | 60.6 | 11.5 (7) | 52.7 | 12.4 (7) | 54.3 |
| July | 14.6 (10) | 58.3 | 16.2 (9) | 61.2 | 18.9 (10) | 66.0 | 16.0 (9) | 60.8 |
| August | 18.5 (5) | 65.3 | 20.0 (10) | 68.0 | 17.9 (11) | 64.2 | 19.9 (14) | 67.8 |
| Sept. | -- | -- | -- | -- | 16.3 (3) | 61.3 | 19.5 (7) | 67.1 |
| Grand Average | 14.0 (23) | 57.2 | 17.6 (26) | 63.7 | 16.6 (31) | 61.9 | 17.4 (37) | 64.0 |

waters were, of course, much warmer than those of June as demonstrated by the bottom temperatures that ranged from 8.5° to 11.4° (47.3° to 52.5° F.) in the fall and from 6.2° to 6.6° (43.2° to 43.9° F.) in the spring.

As the waters began to cool in the fall the temperatures approached uniformity at all depths as indicated by the difference between the bottom and surface temperatures which averaged 7.4° (13.3° F.) during September 21-25 and 3.0° (5.4° F.) during September 30-October 4. On the last date the temperatures ranged from 10.2° (50.4° F.) at the bottom to 12.6° (54.7° F.) at the surface. This reduction of temperatures eliminated the thermocline that had shifted in September between 8 and 25 meters (26 and 82 ft.) and between 15.3° and 8.9° (59.5° and 48.0° F.), although it had covered a range of only about 3 meters (10 ft.) in depth and 3° to 5° (5° to 9° F.) that averaged 3.5° (6.3° F.).

## COMPARISONS BETWEEN THE DATA OF 1932 AND OF 1930 AND 1931

In order to determine whether the data of 1932 differed very much from those of 1930 and 1931, the records of adjacent areas should be compared for about the same time of the year. The Upper Lake Michigan data of 1932 should then be compared with the records of 1930 and 1931 that were obtained in the areas off the Ludington-Frankfort and Manitowoc-Kewaunee shores. The number of records is shown in parentheses.

The surface temperatures of the shallow and deep waters averaged higher in 1932 than in 1930 and 1931 during the comparable periods of June-September, except in July when the temperatures of both waters averaged higher in 1931, not in 1930, than in 1932. The general averages are shown in the left table.

The average depths of the 5-degree (41° F.) water were greater in June of 1930 and 1931 than in 1932. In the other months the depths were greater in 1932 in both waters. The general averages are shown in the table below.

The monthly bottom temperatures of the deep stations averaged consistently 0.1° (0.18° F.) higher in 1932 than in 1930 and 1931 during June-August and 0.4° (0.72° F.) higher in September in 1932 than in 1931. In general the 1932 temperatures of the shallow stations averaged 0.25° (0.45° F.) lower than in 1930 and 1931 in June but 0.25° (0.45° F.) higher in July and 1.05° (1.89° F.) in August.

The monthly average depths of the thermoclines were consistently greater in 1932 than in 1930 and 1931 as shown in the upper table on page 33.

The monthly average temperatures of the 1932 thermoclines were approximately the same as those of 1930 and 1931 during the months when comparable data were available. The tabular materials are shown in the lower table on page 33.

| Month | 1930 M. | 1930 Ft. | 1932 M. | 1932 Ft. | 1931 M. | 1931 Ft. | 1932 M. | 1932 Ft. |
|---|---|---|---|---|---|---|---|---|
| June | 29.6 (8) | 97 | 23.8 (7) | 78 | 31.4 (7) | 103 | 23.0 (7) | 76 |
| July | 31.2 (8) | 102 | 43.3 (9) | 142 | 33.6 (10) | 110 | 42.2 (9) | 138 |
| August | 46.5 (4) | 153 | 50.0 (8) | 164 | 33.0 (11) | 108 | 50.0 (11) | 164 |
| September | -- | -- | -- | -- | 26.7 (3) | 88 | 58.6 (7) | 192 |
| Grand Average | 33.6 (20) | 110 | 39.9 (24) | 131 | 31.5 (31) | 103 | 44.1 (34) | 145 |

| Month | Depth in meter and feet | Average depths of the thermoclines | | | |
|---|---|---|---|---|---|
| | | 1930 | 1932 | 1931 | 1932 |
| June | M. | -- -- | -- -- | 11.0-13.0(2) | 13.0-15.0(3) |
| | Ft. | -- -- | -- -- | 36.1-42.6 | 42.6-49.2 |
| July | M. | 10.0-15.5(2) | 18.0-24.0(3) | 13.3-18.0(8) | 19.8-25.2(4) |
| | Ft. | 32.8-50.8 | 59.0-78.7 | 43.6-59.0 | 65.0-82.7 |
| August | M. | 16.3-19.6(3) | 21.5-26.0(10) | 14.2-18.2(11) | 20.9-25.6(14) |
| | Ft. | 53.5-64.3 | 70.5-85.3 | 46.6-59.7 | 68.6-84.0 |
| September | M. | -- -- | -- -- | 13.0-17.3(3) | 22.2-26.9(7) |
| | Ft. | -- -- | -- -- | 42.6-56.8 | 72.8-88.2 |

The data indicate that the waters of the upper lake were generally warmer during midsummer at all depths in 1932 than in 1930 and 1931 in the adjacent lower regions.

The Green Bay bottom temperatures were noticeably higher than those of northern Lake Michigan during the comparable periods of the year. The temperatures of the period, September 18-October 5, averaged 9.2°(3) (48.6° F.) in 1930 in Green Bay and 4.0°(3) (39.2° F.) in 1931 off the Kewaunee and Ludington shores. During the periods of May 13-21 and June 6-15 the temperatures averaged 5.9°(9) (42.6° F.) in 1932 in Green Bay, 3.8° (4) (38.8° F.) in 1931 off the Ludington shore, and 4.0° (9) (39.2° F.) in 1932 in Upper Lake Michigan.

The surface temperatures of Green Bay were also higher in 1932 than those of northern Lake Michigan during the spring periods, but lower in the fall of 1930. The fall temperatures averaged 14.2°(3) (57.6° F.) in 1930 in Green Bay and 18.0° (3) (64.4° F.) in 1931 off the Kewaunee and Ludington shores. The May temperatures averaged 6.5°(5) (43.7° F.) in 1932 in Green Bay and 4.0°(2) (39.2° F.) in 1931 off the Ludington shore. The June temperatures averaged 14.3°(4) (57.7° F.) in 1932 in Green Bay, 7.0°(2) (44.6° F.) in 1931 off the Ludington shore, and 11.1°(9) (52.0° F.) in 1932 in Upper Lake Michigan. The relatively shallow and enclosed waters of Green Bay may account for its noticeable variation from the northern Lake Michigan temperatures during the spring and fall.

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| Month | Temperature | Average temperatures of the thermoclines | | | |
|---|---|---|---|---|---|
| | | 1930 | 1932 | 1931 | 1932 |
| June | C° | -- -- | -- -- | 8.8-11.9(2) | 8.8-12.0(3) |
| | F° | -- -- | -- -- | 47.8-53.4 | 47.8-53.6 |
| July | C° | 8.6-15.2(2) | 8.7-15.9(3) | 9.3-16.5(8) | 7.8-14.8(4) |
| | F° | 47.5-59.4 | 47.7-60.( | 48.7-61.7 | 46.0-58.6 |
| August | C° | 10.9-15.8(3) | 10.5-16.6(10) | 8.5-15.6(11) | 10.3-16.6(14) |
| | F° | 51.6-60.4 | 50.9-61.9 | 47.3-60.1 | 50.5-61.9 |
| September | C° | -- -- | -- -- | 8.5-13.4(3) | 11.0-12.3(7) |
| | F° | -- -- | -- -- | 47.3-56.1 | 51.8-54.1 |

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